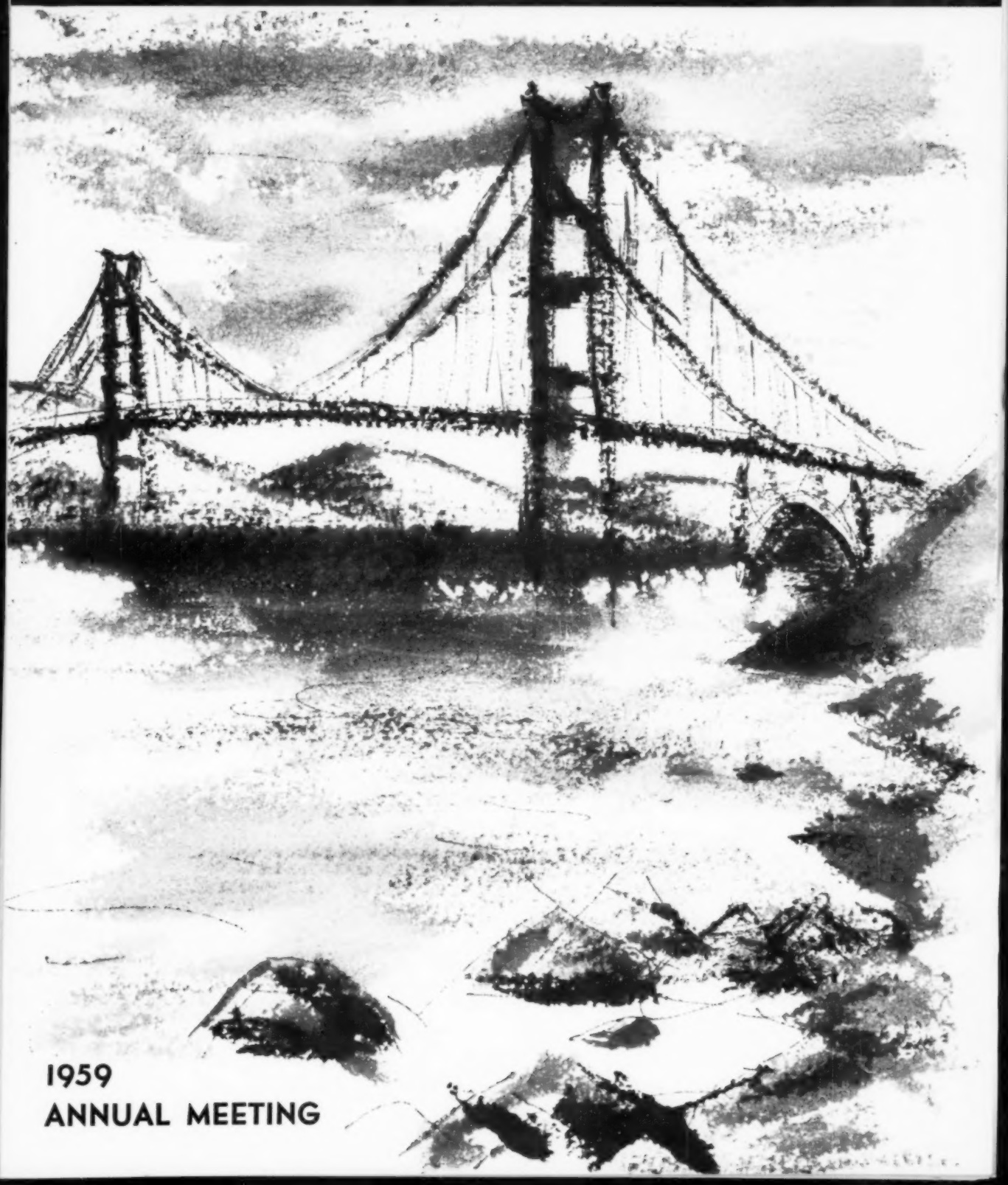
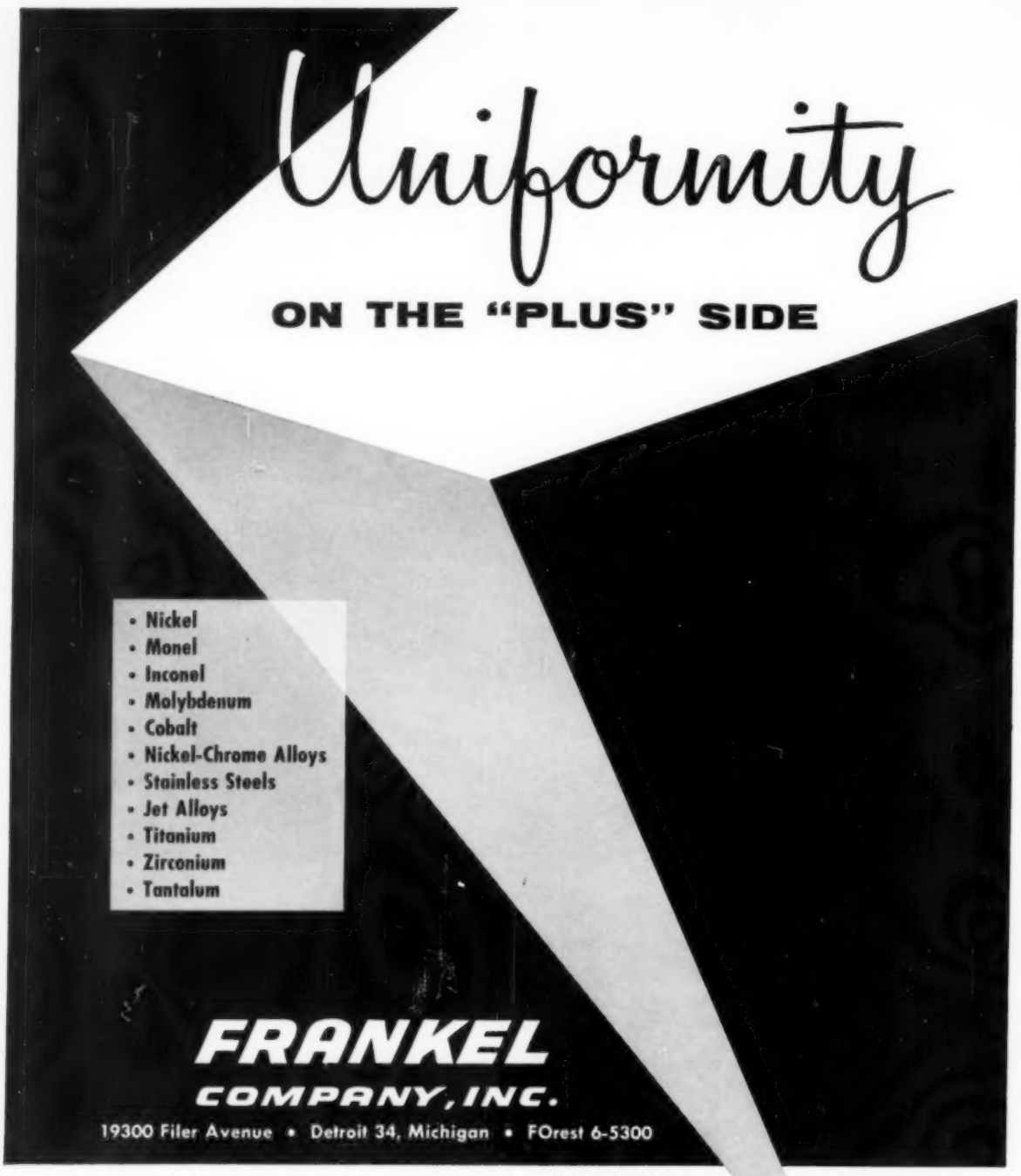
JOURNAL OF

METALS

FEBRUARY 1959



1959
ANNUAL MEETING



Not a single piece of scrap making up your shipment of secondary alloys from Frankel contains less than the amount of alloying agents you specify. This means that the average content of the alloying agents is to the maximum side of your specification.

That's your standard Frankel bonus.

You pay nothing for it.

No wonder more and more buyers of secondary special alloys are turning to Frankel.

JOURNAL OF

METALS

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February, 1959

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PERSONNEL

► These items are listings of the Engineering Societies Personnel Service, Inc. This Service, which cooperates with the national societies of Civil, Electrical, Mechanical, Mining, Metallurgical, and Petroleum Engineers, is available to all engineers, members and non-members, and is operated on a nonprofit basis. If you are interested in any of these listings, and are not registered, you may apply by letter or resume and mail to the office nearest your place of residence, with the understanding that should you secure a position as a result of these listings you will pay the regular employment fee of 5% of the first year's salary if a non-member, or 4% if a member. Also, that you will agree to sign our placement fee arrangement which will be mailed to you immediately, by our office, after receiving your application. In sending applications be sure to list the key and job number.

When making application for a position include eight cents in stamps for forwarding application to the employer and for returning when possible.

A weekly bulletin of engineering positions open is available at a subscription rate of $3.50 per quarter or $12 per annum for members, $4.50 per quarter or $14 per annum for non-members, payable in advance. Local officers of the Personnel Service are at 8 W. 40th St., *New York 18*; 57 Post St., *San Francisco*; 84 E. Randolph St., *Chicago 1*.

— MEN AVAILABLE —

Chemical Engineer, M.Ch.E degree, age 29. Eight years, research, development, and processing engineering in the fields of hydrometallurgy, filtration, and heat transfer, including 1½ years in supervisory research position in extractive hydrometallurgy of non-ferrous metals. Desire responsible research or process engineering position. Prefer East. M-203.

PHYSICAL METALLURGISTS

Here is your opportunity to grow with a young, expanding subsidiary of Ford Motor Company. Outstanding career opportunity is open in Aeronutronic's new RESEARCH CENTER, overlooking the Pacific at Newport Beach, California. You will have all the advantages of a stimulating mental environment, working with advanced equipment in a new facility, located where you can enjoy California living at its finest.

PHYSICAL METALLURGIST, for research and development in high temperature materials. Advanced degree and minimum of 3 years experience, including X-ray diffraction, metallographic inspection and experimentation with ultra-high temperature physical properties. Familiarity with powder metallurgical techniques preferred.

Qualified applicants are invited to send resumes and inquiries to Mr. K. A. Dunn, Aeronutronic Systems, Inc.

AERONUTRONIC SYSTEMS, INC.

a subsidiary of Ford Motor Company
1234 Air Way, Bldg. 18, Glendale, Calif.
CHapman 5-6651
Newport Beach, Glendale,
Santa Ana and Maywood, California

— POSITIONS OPEN —

Assistant or associate professorship, dependent upon qualifications and experience. Ph.D. desired for expanding graduate program in physical metallurgy with emphasis on the physics of metals. Position offers wide scope for training of graduate degree candidates through teaching and research. Opportunity to augment salary through organized and supported research on campus. Location, West. W6911.

Smelter Engineer, B.S. in metallurgical, mechanical, or civil engineering; at least five years experience required in pyro-metallurgical industry, preferably copper smelting, two years of which should have been in supervisory position. Location, South America. F6902 (b).

Staff Consultants with considerable metallurgical processing experience in non-ferrous fields: a) ore dressing, flotation, beneficiation; b) smelting and refining of nickel, aluminum, titanium; c) electrolytic zinc, copper, nickel. Salaries open. Location, Midwest. W6881.

Metallurgical Sales Engineer, degree in metallurgy or chemical engineering with minimum of three years sales background experience in electric steel manufacturing. Will represent company in metallurgical sales accounts. Travel approximately 60 pct away from home office but seldom for weekends. Headquarters, eastern Pa. W6869.

Metallurgist, graduate, to start and supervise manufacture of nonferrous hardeners and specialty alloys. Salary open. Location, eastern US. W6862.

Sales Engineer, metals div., young, preferably metallurgical graduate, to contact and consult with clients regarding problems on rolled strip and ingot soft metals. Considerable travel. Salary: $6000 to $7200 plus expenses. Location, N.Y.C. W6859.

Sales Engineer, graduate metallurgist preferred, but will consider chemical graduates or physical chemists with two to three years experience in sales or metallurgical laboratory or production work. Training and orientation will vary with experience and will include some time in the process development and product development laboratories. Duties will include repeat sales, analysis of customer problems, and providing technical advice and missionary work to develop commercial sales for new products. Will be responsible for selected group of products such as new alloys, pure metals, metal chemicals, and others, Straight salary with expense account. Some travel. Excellent opportunity. Headquarters, N. Y. State. W6858.

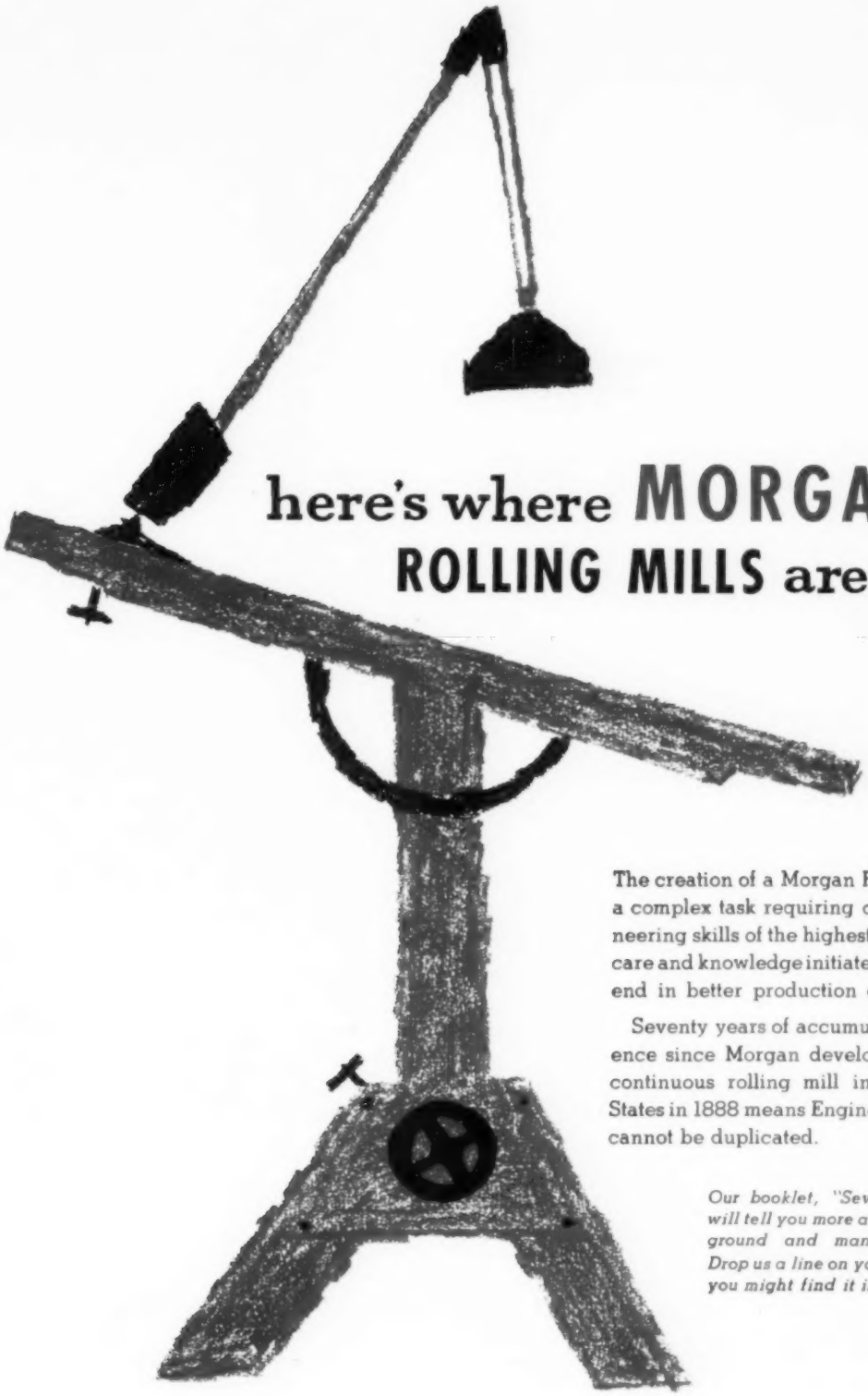
Research Engineer, graduate metallurgical, chemical, or ceramic engineer with two to three years industrial experience, to be responsible for basic research problems related to glassing conditions, metallurgical heat treatment, furnace atmosphere, controls, etc. Salary commensurate with qualifications. Location, upstate N. Y. W6846.

Process Engineers, degree in mechanical, electrical, or metallurgical engineering, with some work experience related to metal working preferred. Should have minimum of four to five years industrial experience. Company is specialist in the development and manufacture of nickel-chromium and nickel-copper resistance wire, strip, and special castings. Salaries open. Location, N. Y. metropolitan area. W6829.

Teaching Position for metallurgist or metallurgical engineer, preferably with experience in nuclear reactor materials, to teach and supervise graduate research in physical metallurgy and metallography. Excellent opportunity for research and professional development in progressive engineering school. Salary and rank commensurate with qualifications. Location, Southeast. W6828.

Manufacturing Manager for company manufacturing lighting equipment. Must be experienced in sheet metal finishing and forming and be strong in production control. Will have 400 employees under supervision. Salary: $20,000 to $25,000. Location, N. Y. metropolitan area. W6818.

Field Sales Engineer, degree in metallurgy or minerals beneficiation preferred, for multi-division company. Will be responsible for process equipment sales to the metallic and non-metallic industries. Must have three to five years experience in processing equipment field. Liberal benefits with good starting salary plus incentive based directly on sales efforts. Car furnished and expenses paid. Territory, notheastern area out of N. Y. W6330.



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The creation of a Morgan Rolling Mill is a complex task requiring creative engineering skills of the highest caliber. The care and knowledge initiated at this point end in better production on your mill.

Seventy years of accumulated experience since Morgan developed the first continuous rolling mill in the United States in 1888 means Engineering which cannot be duplicated.

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MORGAN CONSTRUCTION COMPANY
WORCESTER, MASSACHUSETTS

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RM-74

"We block with the silicon in this new chrome"

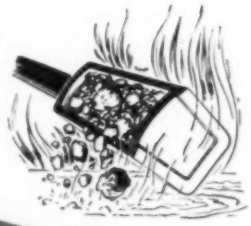
Savings in chromium and silicon costs for open-hearth steels can be made with new ELECTROMET high-silicon refined chrome. A very low-cost source of chromium, the alloy also provides 11 per cent silicon for blocking.

Savings of approximately $1.00 per ton can be made over practices using exothermic ferrochrome in the ladle.

When used for blocking, high-silicon refined chrome dissolves readily and gives tight blocks for the full time required with no phosphorus reversion. Consistently high chromium recoveries have been reported. For further details, contact your UNION CARBIDE METALS representative.

UNION CARBIDE METALS COMPANY, Division of Union Carbide Corporation, 30 East 42nd Street, New York 17, N. Y.

A one per cent chromium addition adds approximately 0.25 per cent silicon.



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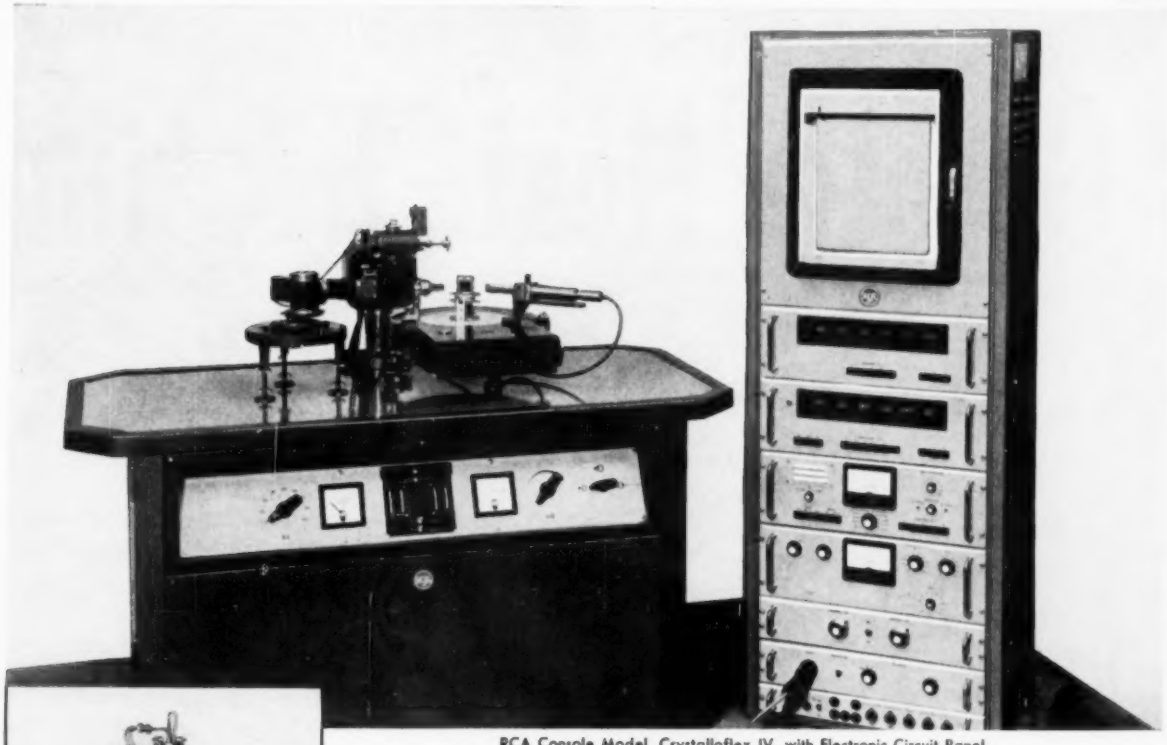
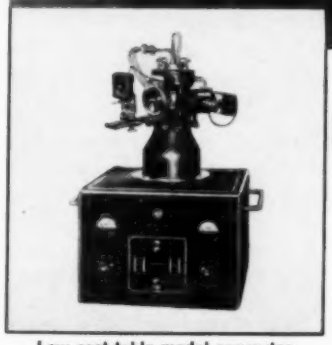
SCIENTIFIC INSTRUMENTS FOR RESEARCH AND DEVELOPMENT



RCA Console Model, Crystalloflex IV, with Electronic Circuit Panel.



Low-cost table model generator
designed for all types of film work including stress analysis.

Only RCA X-Ray Diffraction and Spectroscopy Equipment Provides Regulated and Filtered DC Power Supply

One of the most significant of the many advanced features incorporated in RCA's Crystalloflex IV is the regulated and filtered DC power supply. This is particularly important to spectroscopists and to diffractionists who require line intensity reproducibility since it provides an X-ray beam stability of 0.3 percent or less and reduces ripple to 40V per MA or less.

Easy changeover from diffractometry to spectrometry, easy access electronic circuit panel and the widest range of accessories and attachments available today, all illustrate the unequalled versatility of this new equipment. Design and construction, as well as performance characteristics, are outstanding.

RCA also offers a compact, low-price, table model generator which can be operated with up to four individually timed cameras simultaneously. This is an ideal instrument for those interested in establishing a basic facility for X-ray diffraction and for laboratories with heavy work loads where it can be used for making film studies, thus releasing more sophisticated equipment for other operations.

In addition to X-ray diffraction and spectroscopy equipment, RCA also offers research scientists the internationally famous EMU-3 Electron Microscope and a new Electron Diffraction Chamber which can be used in all RCA EMU-3 and EML microscopes.

OTHER RCA EQUIPMENTS

- Stress Cameras, Cylindrical Cameras, Flat Cameras, Microradiography Camera, Microradiography Cameras for use with fluorescent x-radiation.
- Guinier Camera and Curved Crystal Monochromator.
- Microfluorescence Analysis Attachment for X-ray Spectrometer.
- Rotating Crystal Layer Line Attachment.
- Pole Figure Goniometer.
- Vacuum Fluorescence Spectrometer.
- Four Window Vertical Tube Holder.

To find out more about this advanced new equipment available only from RCA write: Radio Corporation of America, Dept. P-347, Building 15-1, Camden, N.J.

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Greater Heat-Treating

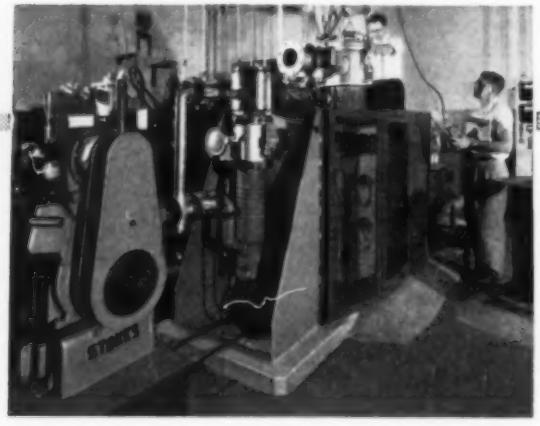
with Stokes Vacuum

Heat-treating processes have taken forward steps and gained new momentum through the advances of vacuum furnace technology. These are but a few examples of industries who now rely on Stokes systems to meet their specific production requirements.

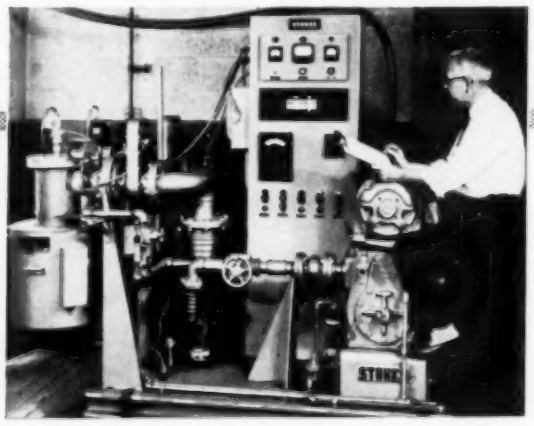
Stokes' extensive design experience and manufacturing facilities combine to make possible these new vacuum heat-treating opportunities. You have a choice of a complete range of types and sizes of furnaces. The systems are offered complete – placing in Stokes a single-source responsibility for performance and reliability.

Stokes offers additional advantages that can contribute to your successful metallurgical programs. Stokes can, for example, deliver a complete turn-key installation – erected, tested and delivered "in operation". Systems also benefit from the use of stock components – facilitating faster delivery. Stokes systems are furnished to do the best possible job at lowest cost to you.

Standard Stokes Vacuum Heat-Treating Furnaces are available for experimental and as full



At The Budd Company's Defense Division, metal components are designed and produced for important and classified nuclear reactor work. Because of the characteristics of the metals used, new procedures were necessary for welding, heat treating and pickling. The Stokes Vacuum Furnace has assumed an important role in these vital processes.



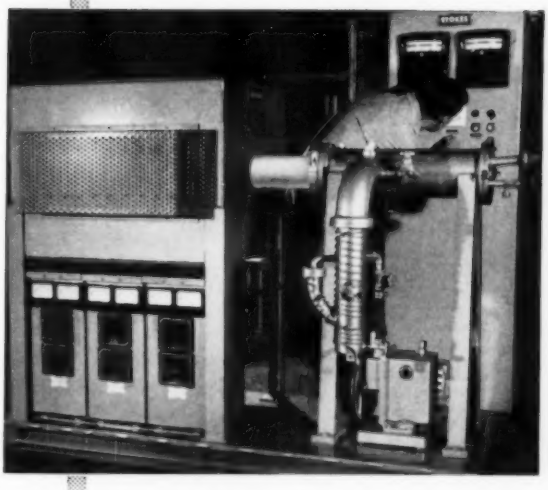
At Associated Spring Corp., Bristol, Connecticut, precision springs finer than a human hair are vacuum heat treated to rigid specifications. Of critical alloys, they require high temperatures. If treated in atmosphere, surface oxidation would be intolerable. A Stokes Vacuum Furnace enables production of springs for even the most delicate instruments.

Progress...

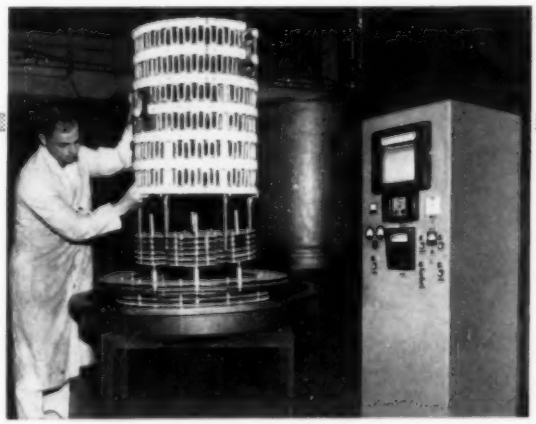
Furnaces

production size systems. Other types are available for melting, refining, casting, sintering, brazing and stream degassing. Special systems can be designed to meet the exact needs of specific operations. All-the-way service, before and after the sale, completes the picture of how well Stokes is equipped to work with you.

You can take full advantage of Stokes' advanced vacuum technology. The Stokes Engineering Advisory Service will assist you in planning and designing a heat treating installation that will best serve your exact requirements. Call Stokes—today.



A resistance-heated, two-zone, high temperature Vacuum Heat-Treat Furnace . . . installed for operation over 2500°F. Available in sizes to 9" I.D., for brazing, out-gassing and heat-treating . . . in both research investigations and small parts production.



A cold wall furnace capable of providing high temperatures at unusually low pressures is one of the most recent developments of Stokes. It is particularly applicable to high temperature solid state processing. Depending on the nature of the application, temperatures up to 2000°C are attainable at sub-micron pressure. Customer built for specific requirements, these furnaces are offered in a wide range of sizes, for research or production service.

In addition, Stokes offers complete laboratory facilities and technical assistance for investigation of commercial heat treating applications where highest temperatures are necessary.

Vacuum Equipment Division
F. J. STOKES CORPORATION
5500 Tabor Road, Philadelphia 20, Pa.

STOKES

Built by
HEVI-DUTY
specialists in
industrial furnaces

NEW TESTING FURNACE

Determines Coke or Ore Strength at Temperatures to 3000° F

Foundry and blast furnace users can be assured of high air blast volume by using only coke which has shown high-temperature crush resistance. The New Hevi-Duty High-Temperature Coke-Testing Furnace determines comparative compression strength of coke or ore pellets under simulated blast furnace conditions.

Here's how tests are made: A sample of coke, cut to a cube of standard size, is placed in the Hevi-Duty furnace. Nitrogen or Argon atmospheres are introduced and the chamber temperature is brought up to and held at 3000° F. Then a hydraulic ram applies measured pressure to the coke cube until the sample collapses. Compression strength in pounds per square inch can be easily determined by comparing the size of the cube tested to the weight applied at the moment of collapse.

Determination of the temperature at which an ore pellet will soften is done in the same furnace by maintaining constant pressure, and increasing the temperature at a set rate.

If your processes could be improved through the use of higher strength coke or ore, put this furnace to work for you.

Further details in Hevi-Duty Bulletin 958.

- Industrial Furnaces Electric or Fuel
- Laboratory Furnaces
- Dry Type Transformers
- Constant Current Regulators

HEVI-DUTY ELECTRIC CO.
Milwaukee 1, Wisconsin

News of EDUCATION

► **The National Science Foundation** announced that 302 science faculty fellowships have been awarded for 1959. The awards offer college and university science teachers the opportunity to further their studies so as to enhance their teaching ability in the fields of mathematics, science, and engineering.

The Science Faculty Fellows were selected on the basis of ability as indicated by letters of recommendation, academic and professional records, and other evidence of attainment and promise. In order to be eligible applicants were required to have a baccalaureate degree or its equivalent, demonstrated ability and special aptitude for science teaching and advance training, and three years of full-time teaching at the college level.

The Foundation, in addition, announced that 82 senior postdoctoral fellowships were awarded for the coming year. Granted to scientists of demonstrated ability and special aptitude for productive scholarships in the sciences, they include 39 in the field of life sciences and 40 in the physical sciences.

► **Argonne National Laboratory** is offering a program of summer employment for undergraduates, graduate students, and faculty members. Undergraduates will be selected for this program on the basis of credits earned, grades, references, and experience. Deadline for undergraduate application is February 15th and further information and application forms may be obtained by contacting: *Employment Office, Argonne National Laboratory, P.O. Box 299-SA, Lemont, Ill.*

Application for employment by graduate students and faculty members should be submitted by February 15th. Contact the *Professional Personnel Office, Argonne National Laboratory, P.O. Box 299, Lemont, Ill.*

► **The University of Arizona's College of Mines** has announced a symposium and educational program on the Application of the Fluidizing Reactor to the Mineral Industry.

The educational program will be held from Monday, February 23rd through Friday, February 27th; it

(Continued on page 96)

NOW YOU WILL KNOW THEY ARE FROM GREAT LAKES CARBON

This New Emblem is your assurance of carbon and graphite products—production engineered to the highest standards of quality.

The emblem is being introduced in all of our packaging — in electrode end protectors, nipple cartons, palletized anodes, palletized carbon brick, and drums of carbonaceous materials.

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GRAPHITE ELECTRODES • ANODES • AND SPECIALTIES

With Harbison-Walker Refractories

LONGER SERVICE and INCREASED TONNAGE in the ALL-BASIC open hearth

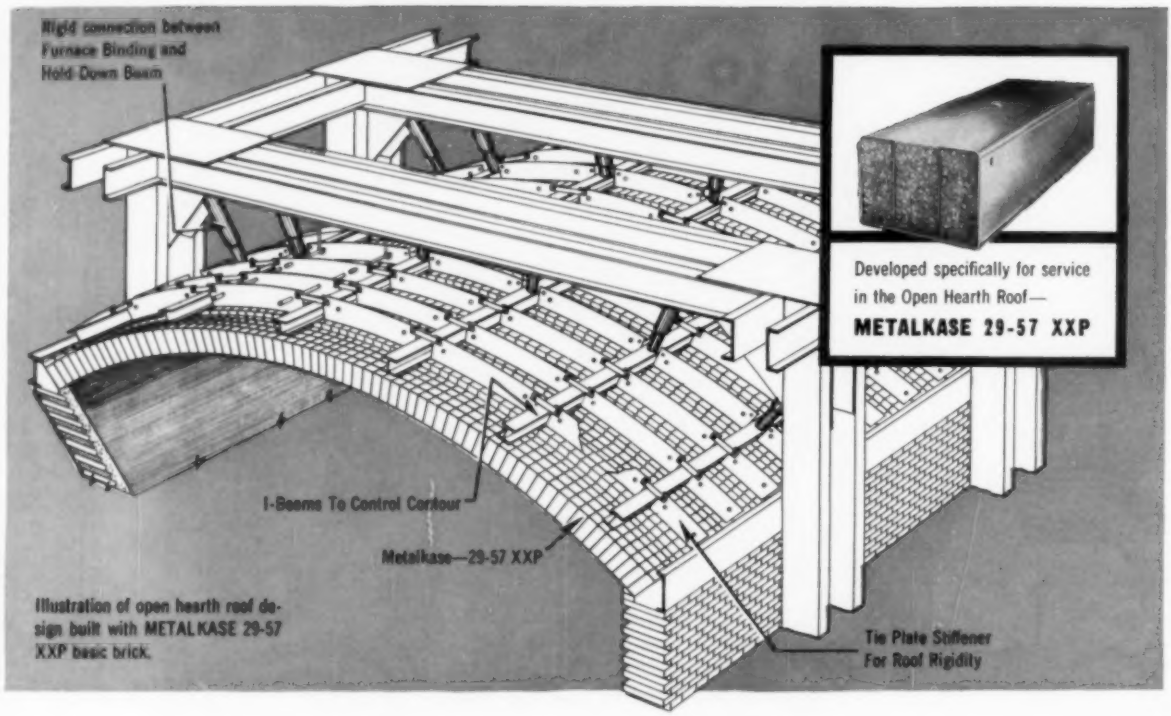

Rigid connection between Furnace Binding and Hold-Down Beam
I-Beams To Control Contour
Metalkase—29-57 XXP
Tie Plate Stiffener For Roof Rigidity
Developed specifically for service in the Open Hearth Roof—
METALKASE 29-57 XXP

Illustration of open hearth roof design built with METALKASE 29-57 XXP basic brick.

Accelerated progress in open hearth steel furnace practice involving larger furnaces, increased use of oxygen and higher rates of production creates demands for superior refractories. With the all-basic open hearth furnace becoming an economical reality, the development of new refractories having decidedly enhanced properties has been necessary. Harbison-Walker conventional and specialized basic refractories are meeting these requirements and winning widest approval.

A fundamental development in the achievement of the all-basic furnace is the metal encased basic brick pioneered more than forty years ago by Harbison-Walker. Through constant research and extensive application experience, rapid evolutionary progress has resulted in the successful use of the metal encased basic brick for open hearth roofs, as well as for other furnace parts.

METALKASE 29-57 XXP internally plated metal encased basic brick is used in both sprung and suspended open hearth roof constructions of all designs with unmatched service records. An exceedingly important contributor to the excellence of this refractory, developed specifically for the purpose, is the high purity magnesia produced by Harbison-Walker from Michigan brines. Fully stabilized as periclase of high density, it is an important constituent of this refractory having outstanding properties for the particular application.

The successful use of basic brick for roofs contributes to greater severity of conditions imposed upon other furnace parts. Harbison-Walker basic refractory products long established with excellent records, together with the newer specialized brands fulfill these rigid requirements for bottoms—walls—and regenerator checkers and make **THE ALL-INCLUSIVE, ALL-BASIC** Open Hearth Steel Furnace a reality.

HARBISON-WALKER REFRACTORIES COMPANY

AND SUBSIDIARIES — GENERAL OFFICES: PITTSBURGH 22, PA.

World's Most Complete Refractories Service

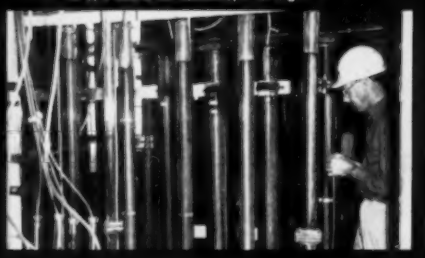
Putting Rare Earths Within Your Reach

tons, pounds or grams—today

These 10 in. columns, 10 ft. high are used for poundage quantities.

Ton quantities are produced in these 30 in. columns, 20 ft. high.

Gram quantity production facilities are made in 2, 4 and 6 in. columns, 4 ft. high.



from the world's largest heavy rare earth producing facilities

Production Facilities: Until recently, the scope of Michigan Chemical's rare earth manufacturing has been classified. Now it can be told that its production units are the world's largest — with nearly 200 ion exchange columns 30 in. by 20 ft. high devoted to the manufacturing of tonnage quantities alone. In another section of this plant are 10 in. columns for the production of the less-abundant rare earth elements such as lutetium, thulium and holmium. Also, in our pilot plant are 2, 4 and 6 in. columns, shown right, which are used mainly for experimental work. A wholly new manufacturing plant is in operation producing rare earth metals in commercial quantities.

Compounds and Metals: Thirteen of the rare earth oxides and metals are available to you in substantial quantities — mainly from inventory. Michigan Chemical Corporation was the first producer to supply most of the rare earth metals in volume.

Price Changes: Our facilities have enabled us to initiate many of the consistent and dramatic price reductions which have occurred in this field. Two years ago, for example, lutetium and thulium oxides were selling at from $100 to $125 a gram. Over a year ago, Michigan Chemical reduced the price of these materials below $30 a gram. *Now* our price is $4.50 a gram in pound quantities. In our role of leading producer, we are continuing every price effort to open the way for more and more research and product applications for these challenging compounds and metals.

With purities up to 99.9+% purity, an assured source of supply and steadily lowering prices, we urge you to investigate Michigan Chemical's heavy rare earth oxides and metals. Phone, wire or write today on your letterhead for technical data, quotations and delivery.

Rare Earths and Thorium Division

MICHIGAN CHEMICAL CORPORATION

635 North Bankson Street, Saint Louis, Michigan

RE-58-4

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RARE EARTH AND YTTRIUM METALS

available in high purity and commercial grades

a report by LINDSAY

If you are interested in the rare earths in metal form for research and production purposes, you will find it helpful to talk with us at Lindsay.

Rare earth and yttrium metals, in *both* high purity and commercial grades, are now available for prompt shipment from our inventory, in experimental quantities.

Both high purity and commercial grades are furnished primarily in the form of ingots or lumps. You will find costs reasonable and advantageous for your research on product development and production operations.

Lindsay has been working with the rare earths for nearly 60 years and is the world's largest producer of salts and compounds of thorium, rare earths and yttrium. Five years ago, Lindsay pioneered the first commercially installed rare earth ion exchange units for the production of separated rare earths in purities up to 99.99%.

HIGH PURITY RARE EARTH METALS

Maximum rare earth impurities – 0.1%

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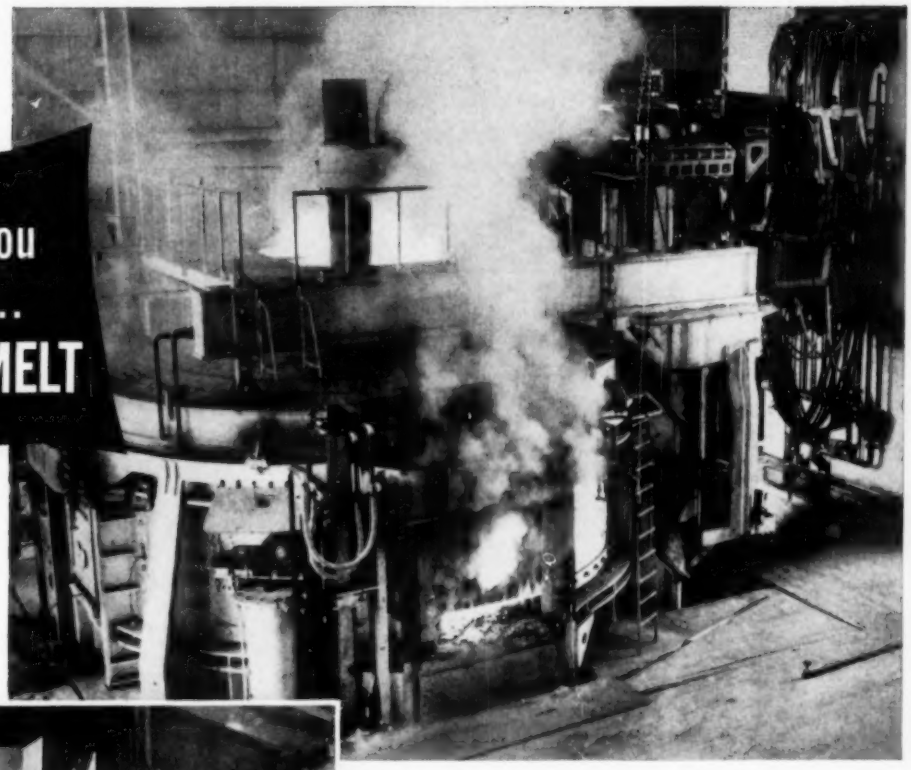

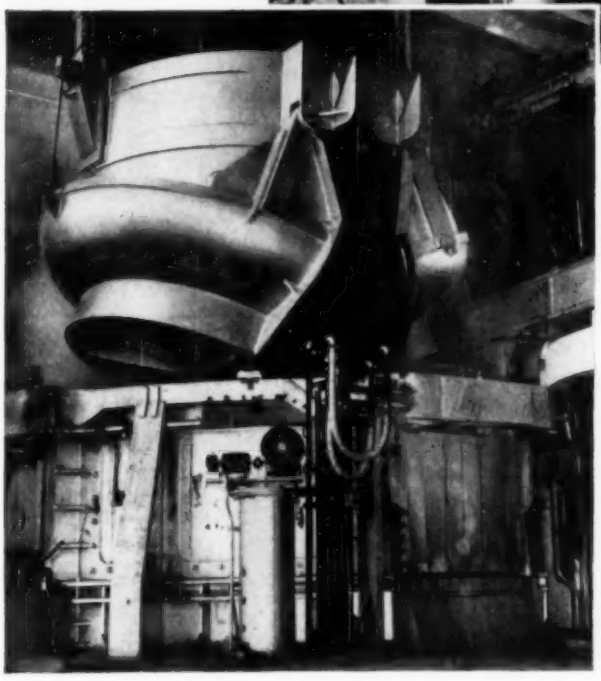

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NICKEL MAKES METALS PERFORM BETTER LONGER

Another steelmaking process?

A bottom-injection process for refining molten pig iron through the use of high-pressure jets of pure oxygen has been developed by Canadian Liquid Air Co., in Montreal, Canada. The process is based on needle jets of oxygen spaced at about 12-in. centers directed into the molten metal through the converter bottom, enabling the highly exothermic reaction zone to be completely enveloped by molten metal, thus dissipating heat to the metal instead of surrounding refractory. Theory is that FeO formed is *scrubbed* by column of molten metal above, forming oxides of C, Si, Mn, and/or P. Result is a minimum evolution of iron oxide fumes, in contrast to lancing techniques. Oxygen pressure is above 400 psi. Canadian states that this process permits treatment to any stage of refining, presumably to finished steel, although present experiments require duplexing.

New name

Electro Metallurgical Co. recently changed its letterhead to Union Carbide Metals Co.—a move to identify the numerous divisions with their parent company. Electro Metallurgical was a pioneer producer of ferroalloys for use in the production of iron and steel.

Refractories laboratory

The Garber Research Center of Harbison-Walker Refractories Co. opened last month 12 miles south of Pittsburgh. Raymond Birch, research director, says that both fundamental and applied research will be stressed, including development of raw products still in the pilot plant stage.

1958 metals markets

The titanium industry in 1958 began a substantial pick-up from the low point of late 1957, reports Titanium Metals Corp. of America. T. W. Lippert, marketing director, says mill shipments averaged slightly better than 200 tons per month. Commercial aircraft use showed a 50 pct increase over 1957. Missile applications, still in the prototype stage, show promise.

Zirconium sponge output in 1958 amounted to about 1500 tons; **Hafnium** production is estimated at 23 tons. Zircon production and imports were less than half of last year's total. Sponge producers approached capacity operation. Melting and fabrication facilities were more than adequate to handle the sponge produced. Westinghouse Electric and Allegheny Ludlum Steel are leading about 30 companies in making zirconium shapes.

Nickel production capacity in the free world (about 525 million lb) almost doubled capacity figures of Korean conflict days, but 1958 consumption figures are expected to show a decrease of 80 to 90 million lb compared with 1957. Principal cause, says International Nickel, was the business recession combined with heavy inventory liquidation by consumers.

Columbium metal domestic production is estimated to have tripled in 1958; **tantalum** shows moderate increase. Several metallurgical plants were completed or under construction, and domestic ore production continued at the high level reached in 1957.

Education

(Continued from page 88)

is designed for engineers who will have control of, or be directly or indirectly connected with the operation of a fluidizing reactor. The symposium will be held on Monday March 2nd, with a field trip on Tuesday, March 3rd, to the new smelter at Hayden, Ariz.

Also news on the campus of the University of Arizona, is the first atomic reactor in Arizona. Known as the TRIGA, this inherently safe nuclear reactor was developed in co-operation with General Atomic, div. of the General Dynamics Corp., and purchased partially through a grant from the US Atomic Energy Commission.

The University's electrical engineering department will use TRIGA in their program of research and teaching which will include reactor engineering, the study of isotope production and use, and instrumentation through the use of isotopes.

► **Ohio State University** has been granted the first accreditation of its curriculum in welding engineering by the Engineers Council for Professional Development. In 1893 courses in welding were started at Ohio State, and from these grew a full curriculum in 1947 leading to a bachelor's degree in welding engineering. Prof. Roy B. McCauley, chairman of the department, feels that this new accreditation will help the field of welding engineering move more quickly into national acceptance as a professional engineering group.

► **University of Buffalo** will name its new chemistry building now under construction the *Edwin Goodrich Acheson Hall of Chemistry*.

Acheson, a distinguished inventor-scientist, invented in 1891 the diamond-like abrasive he called *carborundum*, a major asset in modern industrial production. He also invented chemically pure man-made graphite used extensively in the field of electronics. Working successfully with experiments of colloidal graphite and other minute particles, he also contributed greatly to the development of the lubricant and electronics industry. During his distinguished career he received many honors including the *Acheson Medal* of the American Electrochemical Society in 1929.

► **Northwestern University** is now accepting applications for graduate work in the Dept. of Metallurgy during the Fall semester. A partial listing of subjects offered is as follows: oxidation of metals, radiation damage, sintering, diffusion, physical and semiconducting properties of oxides, small angle X-ray diffraction, and thermodynamic studies of solid solutions.

Fields of study for the daytime program leading to an M.S. and Ph.D. degree are chemical metallurgy, mechanical metallurgy, physical metallurgy, physics of solids, thermodynamics, kinetics, and X-ray diffraction. Fellowships, assistantships, and scholarships are available.

Inquiries may be addressed to *M. E. Fine, Chairman, Graduate Dept. of Metallurgy, The Technological Institute, Northwestern University, Evanston, Ill.*

► **The Pennsylvania State University** is offering a diversified program of seminars for engineers and scientists this summer. Subjects scheduled are Seminar on Reactors and Radioisotopes, Electrical Contracts Seminar, Machinability Seminar, Underwater Missile Engineering Seminar, Plastics Seminar, Research and Management Development Seminar, and Report Writing Seminar.

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EDITORIAL

The Third Year

As an aim for The Metallurgical Society during its third year of existence, I would place above all else the strengthening of its program of publications. We are already in the midst of such a program, but it must be accelerated and we must set our sights higher. The JOURNAL OF METALS must be made a vehicle of the broadest possible coverage and of the greatest possible interest to all metallurgists. I visualize it as becoming a journal which each month is early awaited by the metallurgist. It will be *the* one journal which he reads every month, not so much for the purpose of reading the things that he already knows about his own particular corner of metallurgy, but because of its wide interest and clearly written articles on current and important metallurgical topics over a wide range of subjects.

TRANSACTIONS OF THE METALLURGICAL SOCIETY at the present time holds a pre-eminent position in the field of scientific metallurgical publications. It must be strengthened on the engineering side. The idea that metallurgy is a pure science which flourishes only in ivory towers has never been entertained by responsible metallurgists. Metallurgy is engineering as well as science, and TRANSACTIONS is prepared to recognize this fact and to publish a much larger number of sound metallurgical engineering papers. I have served for two years on the Publications committee and can assure you that this committee deplores the scarcity of engineering papers among those submitted to TRANSACTIONS. If the members of the Society observe, and no one could fail to observe, the heavy emphasis on scientific papers in the TRANSACTIONS as contrasted to engineering, the fault lies not in editorial policy but squarely among the membership of the Society. I urge you who are engaged in the engineering aspects of metallurgy, to prepare practical engineering papers for TRANSACTIONS. Make them brief; make them accurate; adhere to the high standards of AIME; but let us have two or three or five times as many papers of an engineering nature as have been submitted to TRANSACTIONS during the past two years.

The Society's publications cannot prosper without adequate funding. During the past five or more years we have asked and have received emergency help from industry in order to keep our publications program alive. I hope that we can reorganize our program in such a way that the Society can carry its own burden of publications. This reorganization is already in progress, and it is responsible for the change in format of TRANSACTIONS. The Publications committee entered into this change with some reluctance but felt forced to do whatever it could, more nearly to balance its budget. To effect improvements will require increased expenditures. These can be justified only if we can be successful along three lines: 1) most important of all, increased membership; 2) increased reader support and more subscriptions for TRANSACTIONS; 3) conservation of the Society's resources to permit allocation of a larger fraction to the publications program. I ask your aid in all three endeavors.

John Chipman
Incoming President
The Metallurgical Society of AIME

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BOOKS

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High Strength Steels for Aircraft, *American Society for Metals,* 7301 Euclid Ave., Cleveland, $2.95, 1958—Contains papers on chromium ultra high-strength steels, steel castings in air frames, use of steel forgings as high-strength materials for hypersonic weapons, and machining and fabricating high-strength steels. These are just a part of the papers which were presented at the Southwestern Metal Congress, May 1958. •

Nuclear Reactor Metallurgy, by Walter D. Wilkinson and William F. Murphy, *D. Van Nostrand Co. Inc.,* 120 Alexander St., Princeton, N. J., 382 pp., $5.60, 1958—Preliminary material on general metallurgy, followed by a discussion of the problems presented by specific metals (including uranium, plutonium, thorium, beryllium and zirconium) are included in this comprehensive volume. In addition the specialized areas such as metallic materials, liquid metals, the use of ceramics in nuclear technology, and the effects of neutron radiation on non-fissionable metals and alloys are discussed.

Review of Metal Literature, by Marjorie R. Hyslop and C. R. Flagg, *American Society for Metals,* 7301 Euclid Ave., Cleveland, 967 pp., $15.00, 1958—The latest volume of this standard work contains brief annotations on virtually every phase of metals. These annotations are classified primarily by processes and properties, following the *ASM-SLA Metallurgical Literature Classification.* A detailed subject index helps to locate specific aspects of a subject. •

The Chemical Behavior of Zirconium, by Warren B. Blumenthal, *D. Van Nostrand Co. Inc.,* 120 Alexander Street, Princeton, N. J., 398 pp., $11.00, 1958—The chemistry of zirconium as an element and as a component of compounds, interstitial solutions and alloys is interpreted in the light of certain basic rules the author proposes as governing the properties of zirconium.

Conference on the Peaceful Uses of Atomic Energy, Proceedings, cosponsored by the *Japan Atomic Industrial Forum* and the *Atomic Industrial Forum Inc.,* 3 E. 54th St. New York, 318 pp., $5.00—Contains a discussion of the development and uses of atomic energy in Japan and the Far East as well as sections devoted to the economics and technology of power.

The Physical Chemistry of Steelmaking, edited by John F. Elliott, *Technology Press of Massachusetts Institute of Technology and John Wiley & Sons Inc.,* 440 4th Ave., New York, 257 pp., $15.00, 1958—This book makes available a comprehensive survey of recent developments in the physical chemistry of steelmaking. Papers of 39 leaders in the field are reproduced as they were presented at the *Conference on the Physical Chemistry of Iron and Steelmaking* sponsored by the Dept. of Metallurgy of MIT. •

Effect of Surface on the Behavior of Metals, *Philosophical Library Inc.,* 15 E. 40th St., New York, 100 pp., $10.00, 1958—Four papers presented as lectures given at the Institution of Metallurgists Refresher Course, 1957, are compiled in this small book. One of the papers deals with the preparation of surfaces for examination and with modern methods of examining the topography and structure of surfaces. This is followed by a paper that shows how the treatment that a surface has received affects its future chemical behavior.

Nuclear Engineering Handbook, edited by Harold Etherington, *McGraw Hill Book Co. Inc.,* 330 W. 42nd St., New York, $25.00, 1958—Nuclear data, nuclear physics, experimental techniques, reactor physics, and control of reactors are some of the aspects covered in this survey book on nuclear theory and engineering. The material has been edited for practical use by engineers interested in the industrial uses of nuclear energy. •

The Nuclear Handbook, edited by O. R. Frisch, *D. Van Nostrand Co. Inc.,* 120 Alexander St., Princeton, N. J., $8.50, 1958—This handbook contains condensed and tabulated data which is needed in research and the practical application of nuclear science. Among the areas covered are particle accelerators, charged particles, X-rays and gamma rays, neutrons, and ion chamber and counters.

Physical Metallurgy of Uranium, by A. N. Holden, *Addison-Wesley Publishing Co. Inc.,* Reading, Mass., 262 pp., $5.75, 1958—Uranium in this text is studied in terms of its fundamental properties and mechanisms. Radioactivity and nuclear reaction, crystallography, deformation, grain growth, as well as diffusion in uranium systems, are some of the major topics discussed.

Monograph on Zinc to be Published

The American Zinc Institute has announced the coming publication of a comprehensive monograph, *Zinc—The Science and Technology of the Metal, Its Alloys and Compounds.* Tentative publishing date for the 800-page volume is in the late summer or early fall. C. H. Mathewson, former AIME President, is the editor.

The book will give a thorough treatment to every phase of the zinc industry as well as to the scientific considerations upon which the industry is based. Authors of the various sections are men highly regarded in the field.

History, economics, and geology are treated in the first three chapters. The fourth chapter deals with the chemistry and physics of zinc and zinc technology from a fundamental point of view, showing how such considerations have affected modern procedures.

Chapters five through seven, comprising a large portion of the book, discuss in detail the concentration, extraction, and refining of zinc. All present day processes are reviewed, much attention is given to the control of impurities, and the reader is taken right up to the melting and casting of market shapes.

This section is followed with a discussion of the manufacture of zinc oxide, and an exhaustive study on the processing and uses of zinc and its alloys. Included here is a special section of the physical metallurgy of zinc, enhanced by an extensive bibliography. Castings, coatings, wire, pipe, mill products, and miscellaneous products are also discussed.

The remainer of the monograph is devoted to uses of zinc which are of particular importance as an alloying agent, as a reagent in the extraction of other metals; industrial uses of compounds, biological significance, uses as a wood preservative, and uses of zinc in agriculture.

It is expected that this volume will most definitely be a milestone in the literature of this important metal.

The Elevated Temperature Properties of Weld Deposited Metal and Weldments, *American Society for Testing Materials,* 1916 Race St., Philadelphia, Pa., 223 pp., $5.50, 1958—This book published as a special technical publication, provides data on carbon, low-alloyed and austenitic steels, and on complex alloys developed for high-strength temperatures.

Introduction to a Study of Mechanical Vibration, by C. W. Van Santen, *Macmillan Co.,* 650 Fifth Ave., New York, N. Y., 310 pp., $8.50, 1958—Contains reviews of the elementary theory of mechanical vibrations as well as some of the more important vibration problems encountered in practice. This edition also studies in greater detail the vibration amplitude in rotary machines and the principles of, and the instruments for, the measurements of vibrations.

Micro-Indentation Hardness Testing, by B. W. Mott. *Butterworths Scientific Publications,* London, England, 272 pp., $8.40, 1956—This book contains a survey of modern developments in low-load testing beginning with the various concepts of hardness, the relationship of indentation hardness to other physical properties, and the types of apparatus available. In addition, chapters include, among other subjects, the classification of factors involved in determining hardness, and correct application of the load and accurate measurement of the impressions.

(Continued on page 140)

Fellowships and Research Associateships: For advanced work leading to a doctoral degree in physical metallurgy. Course work offered in kinetics, thermodynamics, physics of metals, nuclear metallurgy, theory of alloying, and x-ray diffraction. Research facilities available. Deadline for applications March 1, 1959. Write: Department of Metallurgy, University of Denver, Denver 10, Colorado.

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letters to the editor

This is the initial appearance of a new department in JOURNAL OF METALS designed to be of service to the readers.

Meeting programs

Several people have called my attention to the 4-page Electric Furnace Committee roster and program which appeared in the December issue of the JOURNAL OF METALS. Since we have just received our copies here [12/16], they wondered why space was devoted to the program of a meeting held December 3-5.

I presume that material was received too late for the November issue when you undoubtedly wanted it, and perhaps the December issue was delayed since the JOURNAL is "published the first day of each month." Just as a suggestion, when there is a chance that such material may be out of date to the reader but you feel obligated to publish it, perhaps placement could be made near the back of the issue in place of in front where it attracts undue attention.

Again, I want to commend you for the fine effort you are giving the JOURNAL and the increasing reader interest that this reflects.

Bruce W. Gonser
Technical Director
Battelle Memorial Institute

[The December issue of JOURNAL OF METALS is always distributed at the Electric Furnace Conference, hence carries the program for the conference as well as information on the conference officers, etc.

But we quite agree with you about the lateness of the program for the other readers of the December issue. However, we assure you that with all of the last minute program changes which seem to be necessary, it is quite a struggle to get the information together by the first week of November in time for the December issue. We would publish it earlier, if the conference chairmen could put the program together earlier. In the November issue we printed as much information as was available on the Electric Furnace Conference on page 747.

Actually, it has been the conference programs, their last minute changes, and the general lateness of their receipt here that have delayed one issue after another. This is partially true with the January issue in which we presented abstracts from the Annual Meeting. **Ed.**]

Vanadium metal

The article on ductile vanadium in your September, 1958 issue was most timely since this metal is currently receiving considerably increased attention. The article summarizes in an interesting manner the history of the metal and the present situation with regard to it.

Persons interested in getting further information on vanadium might find it worthwhile to refer also to an article *Vanadium Metal—A New Article of Commerce*, by A[ugustus] B. Kinzel which appeared in *Metal Progress* for September, 1950. The article included tabular data on properties in addition to a summary of the vanadium situation at that time.

L. F. Granger
Manager of Advertising
Electro Metallurgical Co.,
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AIME President Elected to EJC

Dr. Augustus B. Kinzel, President of The AIME in 1958, assumed office as vice president of the Engineers Joint Council on January 16th. Dr. Kinzel is vice president in charge of research, Union Carbide Corp.

Enoch R. Needles, a consultant in civil engineering, was re-elected to the presidency of EJC. Other officers are: E. Paul Lange, secretary, Leroy K. Wheelock, assistant secretary, and E. Lawrence Chandler, treasurer.

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SENIOR METALLURGIST . . . with physical metallurgy, ceramics or related background for research programs concerned with advanced reactor fuels and reactor components. Imagination required to extend the state of the art for ultra high-temperature performance. Candidate should have an advanced degree or equivalent related nuclear materials experience.

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AIME President 1959

Howard C. Pyle, President of The American Institute of Mining, Metallurgical, and Petroleum Engineers for 1959, obtained his first practical knowledge of the oil industry 35 years ago while working as a roustabout in the oil fields during summer vacations from college.

Mr. Pyle was born in Williams, Ariz. April 8, 1904. He moved to Pasadena, Calif., with his parents the following year, and has continued to make his home in the Golden State. A graduate of the Pasadena elemenary and high schools, he attended the University of California, receiving a Bachelor of Science degree in petroleum engineering and geology in 1926. Subsequently, he earned his master's degree in petroleum engineering, and the professional degree of petroleum engineering from the University of Southern California in 1939 and 1941, respectively.

From 1927 through 1942, M. Pyle was employed by the Union Oil Co. of Calif. as an exploration geologist and petroleum engineer with the position of chief production engineer during the latter part of that period. As a geologist he worked in Venezuela and California with occasional assignments in Oregon, Washington, and Canada.

During this period, Mr. Pyle presented technical papers before the AIME and the American Association of Petroleum Geologists, and served as chairman of the American Petroleum Institute Production Div. in California, from 1937 to 1938. He was a member of the Conservation Committee of California Oil Producers Committee and a member of its allocation committee, heading it in 1942.

During World Was II, Mr. Pyle served with the US Army Corps of Engineers, first in Washington, D. C., and then as petroleum officer on General Eisenhower's staff in the European Theater, advancing to the rank of lieutenant colonel. During the early invasion period when Field Marshal Montgomery commanded the allied troops, Mr. Pyle served on his staff, returning to his former post when General Eisenhower assumed direct command in August 1944.

From September 1945 to November 1947, he was vice president of the Bank of America in California, in charge of the bank's oil industry loans. For the next three years he was president of Continental Consolidated Corp., oil producers. Following a short period as an independent petroleum engineer, Mr. Pyle was elected president, director, and chairman of the executive committee of Monterey Oil Co. in November 1951, positions which he holds today.

The new AIME President was elected to membership in the Institute in 1941 and from that time on has been active in its affairs. In 1947 he served as Chairman of the Petroleum Branch, now the Society of Petroleum Engineers of AIME. He was elected to the AIME Board of Directors in 1955, and has continued as a member of the governing group.

Mr. Pyle also is a director of the American Petroleum Institute, the Western Oil and Gas Association, and is a member of the American Association of Petroleum Geologists, Theta Tau, Sigma Xi, and an honorary member of Pi Epsilon Tau.

As President of the Institute, Mr. Pyle feels the objective of mineral industry unity is best served by identifying him as a representative of the Institute as a whole rather than as a member of one of its constituent Societies. This attitude is a significant omen that the affairs of AIME in 1959 will be handled judiciously and efficiently under his control.

Howard C. Pyle

NUCLEAR POWER THROUGH METALLURGY IN FRANCE

Journal of Metals wishes to thank members of the Commissariat a l' Energie Atomique for writing this article exclusively for Journal of Metals. It has been translated from the French and summarized in part.

WHEN the Commissariat à l'Energie Atomique (CEA) was created in 1946, France was already active in the study of radio-active minerals, some of the work dating from ancient research. In 1804, the first uranium mineral known was discovered in the Morvan, near Autun, and called Autunite. Such early reports, while of scientific interest, did not constitute deposits of industrial importance.

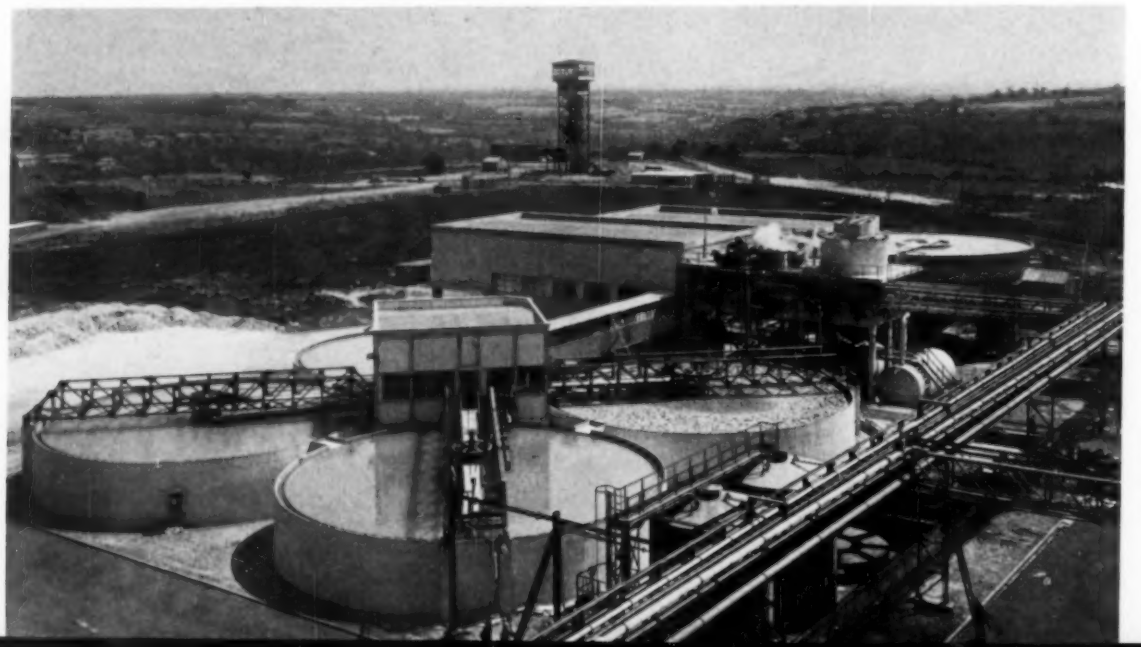
Immediately after World War II, the problem of supplying fissionable raw materials became extremely important for France, because of the impossibility of procuring them from other countries. A rapid inventory of French resources was, therefore, of prime importance.

A preliminary prospecting mission set about carefully constructing a geological map showing regions of possible uranium deposits. This mission utilized a number of novel methods, dictated by geographic and geological conditions: prospecting by airplane and helicopter, by carborn scintillometer, geochemical techniques, and particularly hydrochemical exploration.

Where evidence of important deposits was found, a systematic campaign of prospecting was established. Detailed radiometric map work, geophysical and geochemical prospecting, and drilling of small prospecting drifts were commenced.

Results of this work were felt beginning in 1947, when deposits of high-quality pitchblend were registered at La Crouzille, in Limousin. Fissionable material from this deposit supplied fuel for the first French reactors. Since then discoveries have been

The uranium ore treatment plant of l' Escarpiere in Vendee.



The necessity of supplying increasing quantities of power from unexpandable domestic energy sources has been a problem in France. For this reason, the Country 12 years ago embarked on an extensive program designed to use its own natural mineral resources for the production of nuclear power.

multiplying, and in several years France was able to put into operation considerable mineral resources. An ample supply is anticipated for future years with a continuation of this program. Presently active mining regions are: the west of France in south Brittany (Vendée), the Vosges mountains, the northwest of the Massif Central (La Crouzille), and the northeast of the Massif Central (Forez).

Ore treatment

In France proper, the different minerals districts of CEA are served by four plants, of which three are in operation and one is under construction. These plants either belong directly to CEA or to an affiliate of CEA and a large chemical firm, Kuhlmann.

The plant of Gueugnon (Sud-Morvan) is reserved for treatment of rich minerals. It utilizes new processes in which an intermediate concentrate of calcium uranate base is precipitated directly following acid leaching.

Plants located at L'Ecarpiere (in the Vendée region) and Bessines (in the La Crouzille region), as well as the future plant at Forez, conform to the classic scheme of treatment: attack by sulfuric acid, extraction by ion exchange, and precipitation using magnesium uranate.

The methods of physical concentration, little used for uranium minerals, have been judged economical for certain ores of low uranium content and a plant for electronic sorting has been installed near the plant at Forez.

Table I shows the capacity in the different plants such as they will be at the completion of the present construction program. Concerning France's overseas territory, minerals from the urano-thorico-ferrous deposits of southern Madagascar are concentrated there by gravitometric means. A concentrate containing 60 pct Th and 12 pct U is obtained and shipped to the plant at Le Bouchet in France, where a special installation has been planned for its treatment.

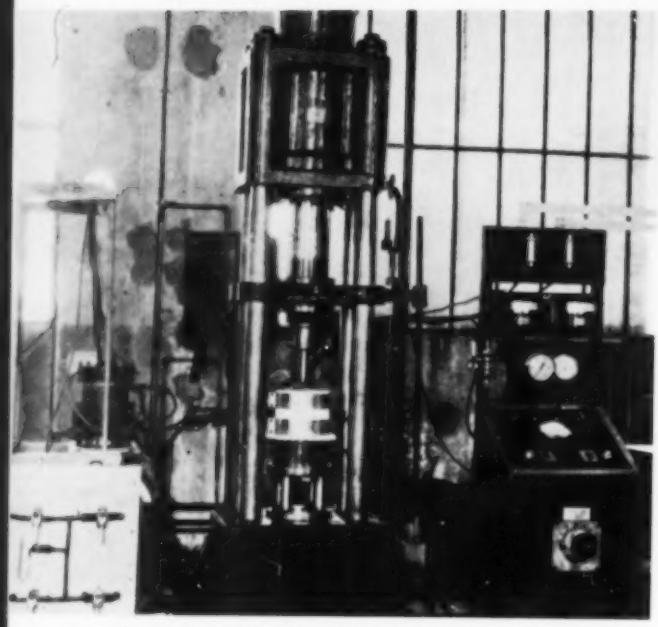
Outside of its own activities, CEA encourages private prospecting in promising regions. Ores assaying above 0.2 pct U are purchased at rates guaranteed to continue until July 1, 1962. Premiums are accorded ores where uranium content is above 0.6 pct. In addition, CEA furnishes technical advice and makes free sample analyses. In 1958, private firms produced some 30,000 tons of marketable ore.

Program of production

Proven French continental reserves guarantee a minimum of 10 years production. If prospecting maintains a sufficient pace, new deposits and extension of deposits actually exploited will assure replacement of worked-out mines. Overseas territories are expected to play an important role as resources of uranium. The deposits at Mounana, in Gabon (French Equatorial Africa), are expected to be producing at least 300 metric tons of uranium by 1962.

Another major effort of the CEA is designed to bring French uranium production costs down to a level competitive with the world market by 1962.

Future production of uranium metal is estimated



Press for extrusion of uranium in gamma phase.

as follows: 750 metric tons in 1959, 1000 in 1960, and 1500 in 1962. Thorium production in the form of the nitrate is now on the order of 300 metric tons of contained thorium.

From concentrate to metal

All uranium concentrates are sent to Le Bouchet, 30 miles from Paris, to be refined into uranium metal. All French requirements for metallic uranium are now covered by the Bouchet plant, but a second uranium plant is under construction at Malvezy, near Narbonne, in southern France, and should be put into operation by July 1959. This should permit French production of 1000 metric tons of uranium in 1960 and, with scheduled expansion, 3000 metric tons by 1970.

Table I. Present and Future Capacities of French Uranium Ore Treatment Plants

Region	Plant	Annual Capacity in Metric Tons of Ore Treated	Annual Capacity in Tons of U Produced	Avg. U Content of Ore Treated, Pct
West of France	L'Ecarpiere	300,000	350	0.100
Northwest of Massif Central	Bessines	600,000[a]	900	0.125
Northeast of Massif Central:				
Forez	Bois Noirs	180,000	330	0.185
Morvan	Gueugnon	30,000	200	0.600
		1,110,000	1,780	

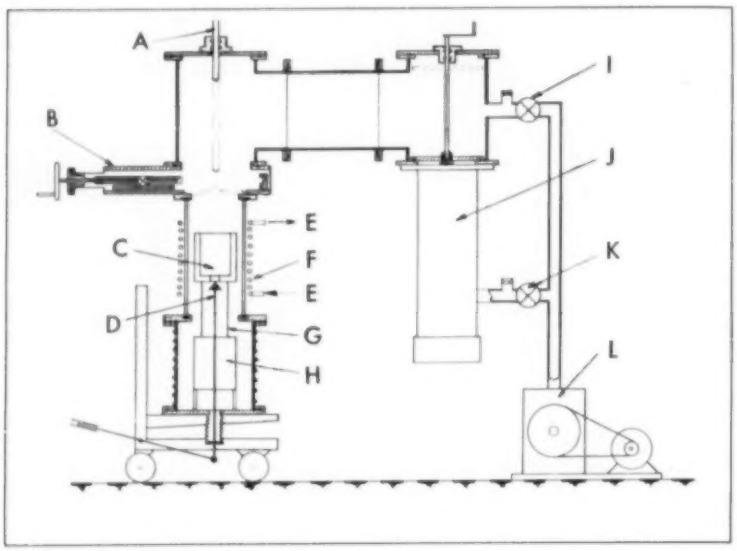
[a] Capacity which will be reached in 1960.

Principle stages of treatment

Uranates are first dissolved in nitric acid by a batch or continuous process according to quality of the concentrates. Dissolution is followed by filtration through a precoated static filter or natural decantation of several days in storage tanks.

Purification of the solution includes solvent extraction followed by a re-extraction with water, then precipitation. Extraction with tributyl-phosphate (diluted to 40 pct in an inert solvent) takes place by a pulsating, countercurrent technique in a vertical column which is filled to the Raschig rings. The solvent charged with uranium goes through a washing with 4N nitric acid at the head of the column. Then it is subjected to a re-extraction with de-mineralized water in countercurrent fashion in a second column where there is no filling or pulsation. The pure aqueous solution of re-extraction is precipitated by ammonia, and the resulting salt is filtered and washed through rotary filters and calcined in a traveling grate furnace at about 400°C.

According to the most recent technique perfected at Le Bouchet, the reduction of UO_3 pellets, and the transformation of UO_2 to UF_4, are accomplished in two vertical furnaces placed one above the other and directly connected. Reduction takes place at about 600°C by cracked ammonia, and fluoridation



Vacuum fusion furnace for fuel element production: A, melting gage; B, vacuum lock for insertion of raw material; C, graphite crucible; D, plug in bottom of crucible; E, cooling water inlet and outlet; F, induction coil; G, crucible support; H, mold; I, valve; J, diffusion pump; K, valve; L, primary vacuum pump.

at about 450°C by an hydrous hydrofluoric acid. The tetrafluoride thus obtained is extracted continuously in the lower part of the unit, thus assuring a regular descent in the furnace. The technique is called the *flowing furnace*.

Transformation of the tetrafluoride into metallic uranium is accomplished by reduction with metallic calcium in an atmosphere of argon. Uranium collects in ingots of 80 kg in fluorspar crucibles placed in the lowest part of the chamber.

Thorium output

Le Bouchet also has a plant for the treatment of urano-thorinate ores from Madagascar; the unit has a capacity of 300 metric tons per year of thorium in the form of the nitrate.

The ores are first treated with nitric acid. After purification by extraction with tributyl-phosphate, uranium and thorium are separated by the precipitation of thorium oxalate, which is converted into hydroxide by caustic soda. This is transformed into nitrate, which is crystallized, dried, and stocked. The uranium remaining in solution during the oxalic precipitation is later precipitated in the form of uranate, which enters the purification cycle of uranium metal.

Fuel element production

Fuel elements are currently made by three methods: 1) vacuum fusion; 2) extrusion in the gamma phase; 3) extrusion in the alpha phase.

1) Vacuum fusion

This process permits production of elements by casting in the desired form, and also promotes degasification of the crude metal. The metal is first brought to the fusion level and later to 1400°C, where it is kept for 20 min to allow for degasification. The heat is poured by removing a stopper in the bottom of the crucible. The metal flows along distributor lines into separate molds.

Electric current for the furnace is furnished by a 100 kw alternator with a frequency of 4000 cps. This is considered a sufficiently high frequency to permit easy heating of the crucible, but it is limited to this low value to avoid strong ionization, which mounts during degasification.

The interior of the furnace consists of a quartz tube with the heating element wound around it and a graphite crucible inside of it. A vacuum of up to 10^{-4} mm of Hg is maintained by a diffusion pump.

The depth of penetration of the current in the walls of the crucible is high at the frequency chosen, thereby producing effective heating. The crucibles are coated with alumina or thoria to prevent prolonged contact between the liquid metal and graphite. The molds are either graphite or steel, and the distributor is graphite.

2) Extrusion in gamma phase range

The gamma phase of uranium exists from 780°C to the point of fusion, but within this temperature range oxidation of uranium is promoted. In addition, a uranium-iron eutectic is formed at 725°C. Consequently, all operations are performed in an argon atmosphere, and contact between hot uranium and iron is avoided through the use of graphite.

An extrusion temperature of 950°C was chosen because the risk of carburizing is low at that point. Extrusion is accomplished in three steps: 1) heating of the vacuum-cast billet to 950°C in an electric furnace under argon—this takes about 2½ hr; 2) extrusion in a press with the reception of the element in a cooling tube filled with argon; 3) cooling in a tube for at least 1½ hr.

The billet is first placed in a stainless steel sleeve coated with pulverized or colloidal graphite. The extrusion die is made of tungsten carbide, a material which is not attacked by uranium and maintains a good mechanical resistance at the working temperature. The press is vertical, pressure is 80 metric tons, and the container is heated electrically to 500°C.

Extruded bars are machined by a classical lathe, the bars first being preheated to 200°C and protected against oxidation by a coating of silicon grease.

3) Deformation of alpha uranium

Extrusion, rolling, and forging can all be done with equal ease in the alpha phase region, i.e., above 500°C. The metal to be worked can be encased in copper sheeting 1 mm thick. An electronic soldering process perfected at Saclay is used to fabricate this sheeting. This permits the hermetic sealing of billets under vacuum and assures that the hot deformation will have perfect protection.

Uranium alloys

CEA has studied many of the alloys of uranium in order to seek means of improving the mechanical characteristics, in particular higher elastic limit and a diminution of the anisotropy of the metal. The alloys U-Al, U-Zr, U-Mo, U-Fe, and U-Cr have been examined.

Metallurgy of Plutonium

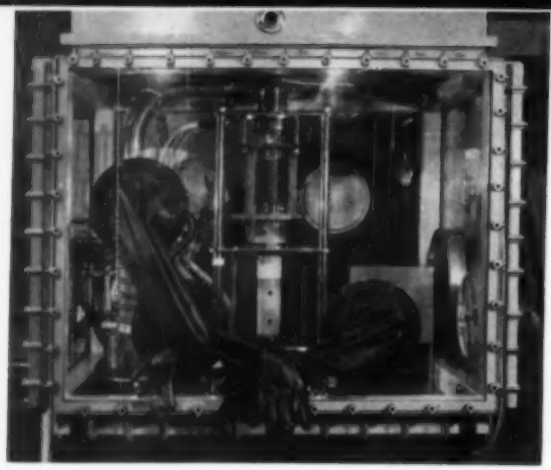
A laboratory for studying the metallurgy of plutonium was placed in operation at the beginning of 1956. At that time, available quantities of plutonium were very small. The major part of French production was reserved for the homogenous reactor *Proserpine*, which went active in 1958 with a quantity of only 250 g of the metal. In spite of the small quantities available, studies of plutonium metallurgy were undertaken.

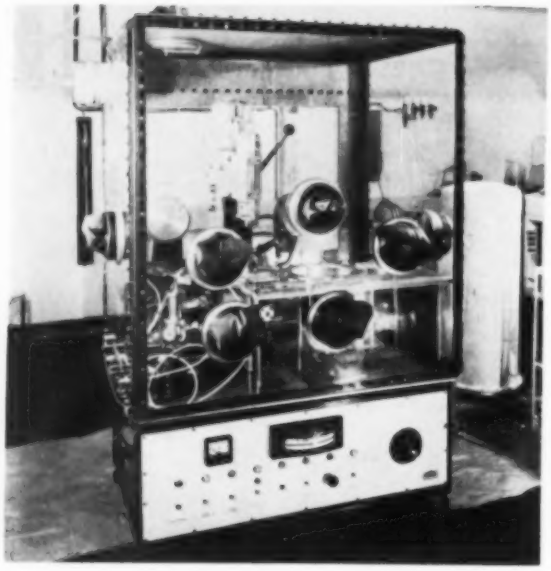
The first problem to be solved was the production of plutonium metal from its fluoride. Reduction by calcium was perfected in the laboratory on masses on the order of 1 g. This mode of preparation was still classified as secret in the other countries at the time French results were published in March 1956. All work on plutonium is carried out in dry-boxes which are maintained at a negative pressure of argon or air.

Activities of the laboratory are classed under four headings: 1) fundamental studies; 2) alloys; 3) ceramics and cermets; 4) technology of fuel elements.

1) Fundamental studies

Certain basic properties of the pure metal have been studied, notably its allotropy, and results have already been published. Dilatometric techniques and precision thermal analysis were used. Only a small portion of present activity is on these studies, but precise determination of plutonium's thermal-electric power is one of the objects of current work.





Top, dry box for the production of plutonium from its fluoride, capacity 50 g Pu. Middle, Press for production of plutonium wire in gamma phase. Bottom, dilatometer in plutonium laboratory.

2) Alloys

The object of alloy studies is fabrication of nuclear fuels for thermal reactors and fast reactors. Production of these alloys is accomplished in resistance furnaces in the case of low-melting alloys like Al-Pu. Melting at high frequency under vacuum is also employed when the melting temperatures are high, since this has the advantage of allowing shape-casting of the metal. Arc melting resolves all problems of crucible and melting temperature, but it has the disadvantage of producing the metal in the form of a button, which is poor for dilatometric measurements. After production and heat treatment, the alloys are examined by classic methods.

Research in progress includes problems of recycling of plutonium in a thermal reactor, studies of alloys such as Pu-Al (results of which have been published), and examination of fuels for fast reactors. At the present time, efforts are being concentrated on tertiary alloys containing plutonium and uranium. It is expected that fuel for the fast reactor *Rapsodie*, currently being planned by the CEA, will result from this work.

3) Ceramics and cermets

An important section of the laboratory is devoted to sintering metals and ceramics, particularly when alloys are difficult to make by fusion or to shape by deformation or machining. Sintering of both the oxides and carbides of plutonium is also being studied.

4) Technology

Metal production: Plutonium metal is produced from the fluoride PuF_4. This is agglomerated under pressure with shavings of metallic calcium. The pellets thus prepared, are heated in vacuum in a fluorspar crucible by high-frequency current; the reaction is initiated without using a catalyst. Production efficiency is of the order of 97 pct.

Alloy production: Alloys are generally produced in an arc furnace with a pure argon atmosphere. Heat treatments are carried out in capsules of tantalum or silicon soldered by an arc under argon atmosphere.

Drawing operations: Plutonium can be drawn into wire in the gamma phase at about 350°C without difficulty. Diameter reduction ratios are of the order of five, and the final diameter is 1 mm.

X-ray diffraction: Standard powder dispersion techniques are employed, and Debye-Scherrer patterns are obtained by direct reflection on a metallic surface previously examined with a microscope. The apparatus uses a diffraction chamber of the Seemann-Bohlin type preceded by a curved quartz monochrometer. Chromium radiation is used, since it gives a large dispersion. The apparatus is not in a dry box, but the sample is encased in a portable container provided with a window for X-rays to pass through. The case is decontaminated to a low level prior to examination.

Differential thermal analysis: A very sensitive method of differential thermal analysis has been perfected. It permits analysis of samples weighing a few grams, and measures heat of transformation with equal precision.

French Atomic Reactors

Before World War II, French scientists occupied a brilliant place in nuclear research. Discoveries by Becquerel and the Curies gave evidence of artificial radioactivity in 1934. In 1939, Frederic Joliot-Curie showed that each fission of a uranium nucleus emitted 2 or 3 neutrons, and he predicted chain reactions. M. Francis Perrin calculated the critical mass necessary for the propagation of a chain reaction. Patents describing an atomic pile were taken out by Joliot, Perrin, Halban, and Kowarski. They collected stocks of heavy water and uranium oxide with which to carry on their experiments, but World War II stopped their work.

Consequently, in 1945, France found herself well behind the US, UK, and Canada. However, demand for electric power in France, along with economics of its production, made the prospect of nuclear power too attractive to neglect.

After the raw materials problem had been solved, the CEA immediately began construction of atomic reactors which would use the natural uranium available. Such reactors had to correspond to the limits imposed by this material, particularly strict economy of neutrons through use of metals with low neutron absorption qualities. A second class of reactors used enriched uranium. In these piles, economy of neutrons ceased to be imperative, and one could utilize material whose mechanical or economic qualities presented certain advantages, although they might absorb neutrons to a certain extent.

Natural uranium reactors

The first French reactor, EL 1, went critical in December 1948, at Fontenay-aux-Roses; it was essentially a laboratory instrument. The second reactor, EL 2, was placed in service at Saclay in 1952. It was the world's first reactor to be cooled by pressurized gas. An important experimental reactor, utilizing natural uranium, went critical on Aug. 11, 1958, at Aquilon, and is being used to study reactor geometry. All these installations use a heavy water moderator.

Plutonium-breeding units

The first Five Year Plan of Atomic Development, voted in 1952, provided for the production of plutonium. France could not then undertake construction of an isotope separation plant. Thus, the large reactors for the *Marcoule* establishment in southern France were designed as plutonium-breeding units. It was also decided to equip them with power-generating machinery.

The first of these reactors was G-1, which uses 100 metric tons of natural uranium as fuel, and a graphite moderator with air cooling. It is rated at 37,000 thermal kw with 5000 kw recoverable as electric energy. The second reactor went critical July 21, 1958, and the third, G-3, is scheduled for operation during the first months of 1959. Together, these latter two reactors will produce 60,000 kw of electrical energy which will be distributed through the French system.

G-2 and G-3 each use 100 tons of natural uranium, which is charged and discharged continuously during operation, and 1300 tons of graphite moderator. They are cooled by carbon dioxide under pressure.

Reactors for power production

Although research and development of prototype reactors fell to CEA, Electricité de France is responsible for the realization of nuclear power.

The 60,000 kw EdF_1 will be the first French nuclear installation conceived primarily for power production. It is patterned after G-2 and G-3, and will enter service late in 1959 at Avoine, near Chinon, on the banks of the Loire river. It is the first of a series of power reactors to be constructed by the French power system. Preliminary work on EdF_2, which will produce 170,000 kw, is beginning at Avoine. A new power plant is expected to be placed in construction every 8 months.

Plans for EdF_3 and EdF_4 are still indefinite, but overall programs schedule 850,000 kw by 1965. Paralleling this development, other prototypes are being studied, particularly a heavy-water moderated type capable of power production.

Proserpine: homogeneous plutonium reactor

Anticipating the time when the production of plutonium from reactors at Marcoule will permit the development of nuclear energy from rapid neutron reactors, CEA is building a number of experimental reactors.

The homogeneous reactor, *Proserpine*, which went critical in March 1958, utilizes 250 g of plutonium in the form of sulfate in a solution of 10 l of water. Its objective is to study the minimum critical mass, as well as the safety aspects of a plutonium reactor. It is in operation at the CEA research center of Saclay, near Paris.

Enriched uranium reactors

EL 3 is a high-flux research reactor placed in service on July 4, 1957, at Saclay. Like other research piles, it runs at low temperature and is able to furnish intense radiation to many experiments at the same time, offering the possibility of radioisotope production. Its fuel is uranium enriched to 1.4 pct, moderated and cooled by heavy water; thermal power is 15,000 kw.

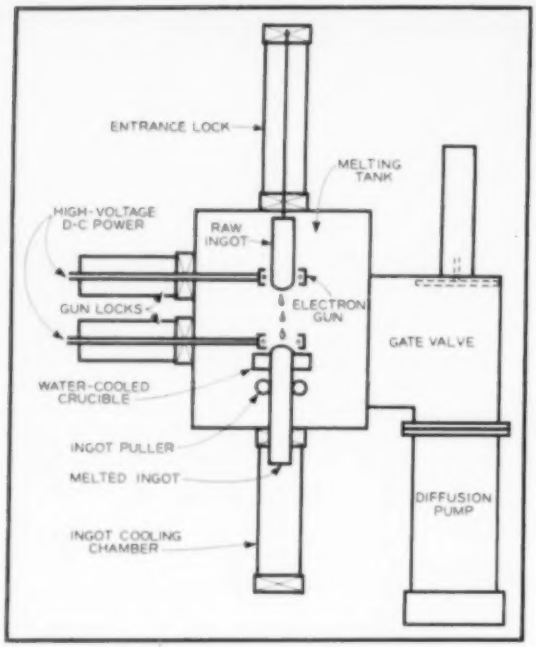
Swimming pool reactors

CEA has three swimming pool reactors in operation or under construction, all for experimental purposes. One of these is *Melusine*, placed in operation in July 1958, at Grenoble, largely for experiments at the university. Its fuel is uranium enriched to 20 pct, moderated and cooled by water; thermal power is 1200 kw. Two other swimming pool reactors are being built in Fontenay-aux-Roses.

The future

The CEA has on its drawing board plans for exploring further the possibilities which plutonium is likely to offer for the production of power. One future reactor of particular interest is *Rapsodie*, a rapid neutron reactor to be cooled by liquid sodium.

Through a coordinated research and production program, the French atomic energy commission, CEA, has, during the past 12 years, brought France to a point where nuclear power is a reality. In the forseeable future, energy from the atom will represent an increasing proportion of power produced from all sources in France.



ELECTRON-BOMBARDMENT MELTING

by Hugh R. Smith, Charles d'A. Hunt, and Charles W. Hanks

"A revolutionary furnace that works like an immense X-ray tube may bring about a major breakthrough in the refractory metals. Its effect on columbium is dramatic. The furnace purifies the metal so highly that a 3-in. bar can be rolled into foil 0.0005-in. thick without annealing. Tungsten that goes into the furnace hard as a rock comes out soft enough to cut with a hack saw."

—FORTUNE Magazine, October 1958

Melting and refining of metals in an extremely high vacuum by bombardment with a stream of electrons may now be considered a production process, since 200-lb ingots of refractory metals are routinely produced by this method. But the techniques are basically different from the methods utilized in laboratory-scale installations described in the literature.[1,2,3,4] These differences relate particularly to the effects of evolved metal vapors and gases on electron dynamics, and the control of these effects to obtain stable process operation.

Furnace operation

Material in the form of powder, sponge, sintered bar stock, or pre-melted ingot is charged into the furnace system through an entrance lock. There are actually several entrance locks on a furnace, each designed specifically to handle a certain type of feed stock. The material is fed into the bombardment area of the upper gun where it is fused and drips into the water-cooled ingot mold. The lower gun is concentric with the ingot mold and maintains a molten pool in the mold into which the feed stock drips.

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The ingot mold is shallow and open on the bottom. As the material solidifies, it is extracted from the mold by the ingot puller at a rate selected to maintain a constant level in the molten pool. After a sufficient length of ingot is cast—in the case of 4-in. columbium ingot this would typically be 4 ft long—it is dropped through a valve into the ingot removal lock. Here it is allowed to cool prior to removal, while another ingot is started in the melting chamber. The whole melting cycle as described above can be directly viewed and controlled by the furnace operator. Very close control of melt additions and ingot retraction can, thus, be achieved.

The most significant portions of the process, from a metallurgical standpoint, are the initial melting and dripping of the feed stock, and the residence time in the molten pool in the ingot mold. The combination of low pressure, high temperature, and lack of contaminating materials in contact with the molten material provides the necessary environment for the purification and devolatilization reactions which make the process useful as a refining technique.

If the feed stock is being melted for the first time in high vacuum, violent outgassing and splattering often occur. The upper gun operates completely independently of the lower gun in this situation, so

Fig. 1—Single gun melting of 3-in. diam tantalum.

that the erratic variations in power input do not interfere with the maintenance of a fully molten pool in the mold. If the feed stock is a previously melted ingot which may be going through remelt for homogenization or further purification, two electron guns are not necessary. A single gun with appropriate focusing shields can be made to divide its electron beam to melt the feed ingot as well as to maintain the molten pool. Maximum melting rates per unit power input are obtained with this configuration. As an example, a melting rate of 250 lb per hr for columbium with 120 kw power input has been achieved.

Gun configurations for either of these types of melting vary widely depending on the characteristics of the melt stock; no single geometry has been found which is generally applicable for melting all metals. This is largely due to the wide variation in evaporation rates of metals at or above their melting points. Evaporated metal vapor in the cathode-anode space has a considerable effect on the electron dynamics, and for production runs the electron guns are configured for optimum operation compatible with the vapor pressure characteristic of the particular metal. Chromium and zirconium serve to illustrate the variation in vapor pressures and evaporation rates for metals with similar melting points. Chromium, at its melting point of 1890°C, has a vapor pressure of about 63 mm Hg which corresponds to an ideal evaporation rate of 0.57 g per sq cm per sec. Zirconium melts at a slightly lower temperature, 1830°C, where it has a vapor pressure of only about 1.2×10^{-5} mm Hg and an evaporation rate of 1.45×10^{-7} g per sq cm per sec. The vastly different metal vapor concentrations above melts of these two metals require completely different melting configurations. Sufficient experience has been acquired so that, in general, cathode-melt stock geometry can be empirically predicted with reasonable accuracy if vapor pressure data for the material are available.

Cathode difficulties: The presence of metal vapor near the electron gun introduces a difficulty which is troublesome in processing some materials. The cathode structure is water cooled and forms an excellent condensing surface for the metal vapor. Even the cathode itself is *cold* compared to certain refractory metals at their melting points. The net result is that the contours of the focusing shields build up with deposited metal and change the operational characteristics of the gun. Also, some materials deposit on the cathode itself. This may change the electron emission characteristics, or, if deposited in sufficient quantity, may alloy locally and change the cathode resistance. In either case, the gun operation is usually impaired. The frequency of such events in production runs is in terms of hours, so that it is necessary to be able to change electron guns easily with a minimum interruption of melting. The furnace is constructed so that the guns may be withdrawn from the melt chamber into a lock, uncoupled as a unit, replaced, pumped down, and reinserted ready for melting operation in 15 min.

The furnace operations described in the preceding paragraphs are completely dependent on two fundamental process requirements: 1) A high-vacuum pumping system of sufficient capacity to maintain an operating pressure of 10^{-4} mm Hg in the chamber while melting and; 2) A stable high-voltage power supply controlled by input current limiting circuitry and cathode emission control features. These two requirements are the key to the electron beam melting process.

Vacuum pumping system

Unfortunately, there are at present, insufficient data to specify accurately the pumping capacity necessary to melt material at any given rate. This simply means that the gas content of the feed stock is, in practice, not known. Analyses accompanying the majority of raw materials to be melted are frequently the product of wet chemistry analysis and

contain no hint of the gaseous interstitial impurities. Condensable vapors of metallic impurities do not appreciably affect the pressure in the vacuum tank, except locally over the melt, and constitute none of the pumping load. Hence, the unknown gas content constitutes the pumping load making it necessary to select a pumping system arbitrarily, matching the melting rate to this selected capacity.

The volume of the melting tank bears little relationship to the nominal ingot size to be produced. Rather, tank volume is determined by the requirements that there be a large cross section, low impedance opening into the diffusion pump, ample space for the internal mechanical and electrical equipment, and room for an operator to enter the tank for maintenance and servicing. Careful design and selection of materials are mandatory so that reliable mechanical and electrical operation can be obtained compatibly with the maintenance of high vacuum in the tank.

A typical pumping system is exemplified by the high-vacuum equipment for a 225 kw production furnace for the processing of 3- to 6-in. diam ingots of columbium, tantalum, and molybdenum. Although the melting chamber has a volume of only 100 cu ft, it is evacuated by two 32-in. oil diffusion pumps which have a combined capacity of 34,000 liters per sec at 10^{-4} mm Hg. Each diffusion pump is backed by a booster pump which is essential for maintaining the diffusion pump backing pressure at very low levels. This low backing pressure prevents excessive back-streaming of pump fluid from the diffusion pumps into the melting tank. The top jet nozzle of the diffusion pump is modified by the addition of a cooled nozzle cap. This feature, in conjunction with the booster pumps for backing, permits operation of the furnace without cold baffles between the diffusion pumps and the tank. The full capacity of the diffusion pumps can, thus, be effectively utilized in maintaining low pressures at high melting rates. Standard mechanical forepumps are appropriately matched to the diffusion and booster pumps to provide roughing and backing capacity.

The vacuum system is fully interlocked to prevent damage to the pumping system in the event of an accident or improper operation.

Melting power supply

Power for melting is supplied as conventional three-phase, full wave rectified, high-voltage direct current. High-voltage, low-current power constitutes one of the advantages of the process, since sources are relatively cheap to build, are very efficient (95 pct and up), and do not require the heavy conductors used in arc and induction furnaces of equivalent capacity. The power requirements for general melting operations vary considerably, depending not only on the melting points of the material but, as indicated previously, on the evaporation rates of the material. The power supply must provide independent voltage and current control so that a required power input can be achieved by a range of voltage-current products. Such flexibility permits high-voltage *start-up* and the subsequent establishment of optimum operating points for the characteristics of the melt stock. Voltages customarily used lie between 4000 and 12,000, and the bombardment current from a typical gun can be varied from 0 to 15 amps.

Stabilization of the power supply is best discussed with reference to the electronic processes occurring during a melt. The basic phenomenon of high-voltage electron bombardment prevents operation under conditions of pressure which are unfavorable with respect to the desired metallurgical results. If the pressure is too high, it is impossible to maintain a high voltage between the cathode and the melt, and a low-voltage discharge will result. Depending on the nature of the discharge, there will either be insufficient power for melting, or the transient current peak will actuate the circuit breakers. Usually the pressure pulses which cause disruption of the power are bursts of gas from the melt stock as it fuses. The pumping system has such high capacity that these pressure bursts have a time constant of the order of fractions of a second.

Steady operation is essentially obtained by providing two means of control over the power input to the melt. A current limiting input to the power supply, as described by Steinmetz,[5] permits establishment of a maximum value of the current which may be drawn from the power supply no matter how the impedance in the gap between the cathode and anode may vary. High-current, low-voltage arcs are thus prevented.

An emission-limiting control on the cathode serves to further stabilize operation, particularly with regard to rapid recovery after a voltage breakdown. Typical circuitry for emission control in this type of application is described by Calverley, et al.[6]

Metallurgical significance of electron-beam melting

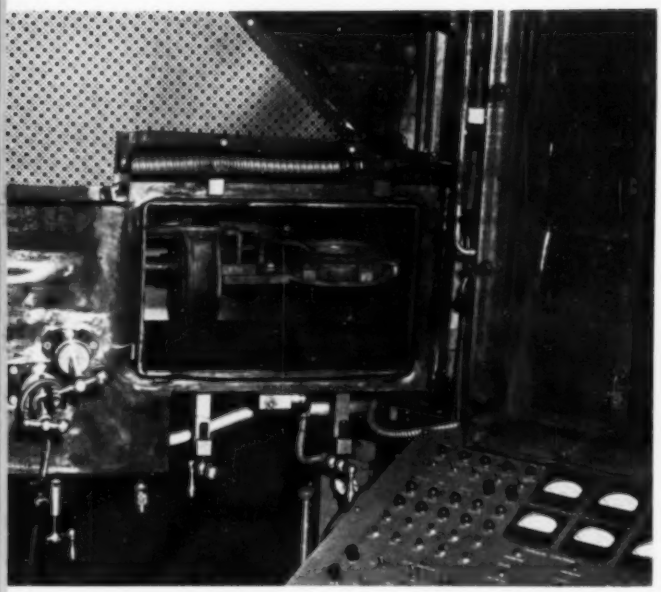
The preceding brief description of the operation of electron-beam melting equipment indicates a degree of technological complication not ordinarily encountered in metallurgical production facilities. Benefaction of the melt stock by electron beam melting must justify the use of the process to establish it as a commercially feasible production technique. The following paragraphs summarize the information presently available on the results of electron-beam melting of various metals.

Changes in the composition of metals and alloys occurring during electron-beam melting are significantly different from changes resulting from other melting systems. This can be attributed primarily to the much higher vacuum existing at the surface of the melt during electron-beam melting. Devolatilization reactions proceed more rapidly and to a greater extent at high-vacuum conditions. The degree of devolatilization during electron-beam melting depends on the residence time of the material in the molten state, the amount of superheat above the melting point, and the nature of the various species in the melt and evaporating from the melt. The degree of purification resulting from these devolatilization reactions is a function of the physical chemistry of each particular system. A general rule used as a guide is that these reactions proceed at economically rapid rates in electron-beam melting until the theoretical equilibrium vapor pressure of the particular species is about 10^{-5} atm.

Alloy composition changes

Changes in alloy compositions resulting from evaporation of metals more volatile than the base metal can be estimated quite closely.

Basic data used in such estimations are primarily the vapor pressures of the pure metal constituents as tabulated, for example, by Stull and Sinke.[7] Of equal importance in the case of aluminum, silicon, boron,



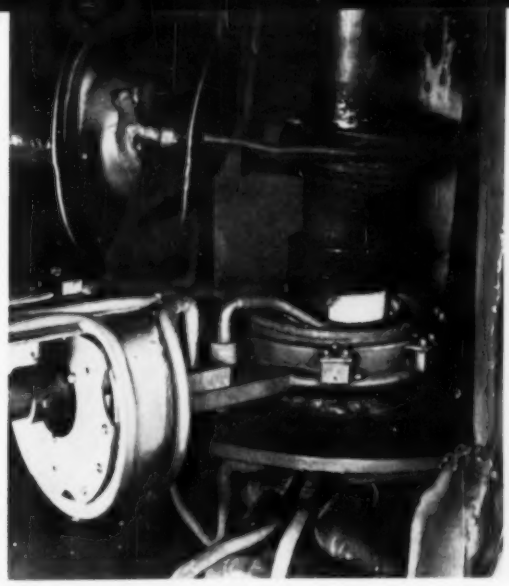


Fig. 2 (left) Electron gun vacuum lock and mechanism. Fig. 3 (above) Interior mechanism in melting tank of electron-beam furnace.

and carbon are the bonding effects between these elements and other metals. Such data as exist on these so-called intermetallic compounds are used as a means to estimate the activity (and thus vapor pressure) of the aluminum, silicon, boron, or carbon above the compound in the pure state. Further reduction in vapor pressure, due to solution of the compound in the molten metal solvents, is then assumed to follow ideal solution laws.

Lack of data on intermetallic bonding between most high-melting-point reactive metals prevents the calculation of bonding effect reductions in vapor pressure. For estimating purposes, ideal solution effects are assumed to occur.

Thus, prediction of the probable composition of a typical alloy processed in an electron-beam melting furnace is made as follows: the vapor pressure of the pure metal constituent at the melting point of the alloy is corrected by ideal solution theory. If intermetallic bonding energy data are available, the vapor pressure is further corrected. If the resulting estimated vapor pressure of the constituent is less than 10^{-5} atm (or less than that of the base metal), then preferential loss of that constituent will not occur. An example of such a case is iron in zirconium, shown on a Cox Chart, Fig. 5. The vapor pressure of iron at 2200°C, corresponding to highly superheated zirconium, is shown to be about 2×10^{-2} atm. Assuming an ideal solution of iron in zirconium at this temperature, the concentration of iron to give a vapor pressure of 10^{-5} atm would be about 5×10^{-3} mol pct Fe, or about 0.03 wt pct Fe in zirconium.

An example of the influence of intermetallic bonding is shown in the case of aluminum in titanium. Fig. 5 shows that 0.1 mol pct Al (about 0.05 wt pct) in titanium gives a vapor pressure of 10^{-5} atm. Yet there is no noticeable loss of aluminum in a *conventional* electron-beam melting cycle on the Ti-6Al-4V alloy. Melting at a rate about ten times slower than normal, however, does reduce the aluminum content of this alloy to 1 or 2 wt pct. The intermetallic bond energy must be sufficient to reduce the vapor pressure of aluminum dissolved in titanium by a factor of about 200, since the base vapor pressure reached at that low melting rate is about 10^{-6} atm.

Lack of data on heats of vaporization of intermetallic compounds prevent the estimation of the vapor pressure of such species, which may themselves be quite volatile even though the individual elements are not.

Deoxidation by volatilization of base-metal suboxides

One of the recent interesting chemical developments, which has found practical application in analyzing the effects of electron bombardment melting, is the observation of metal suboxide species in the atmospheres of various stars. Except for titanium, the volatilities of reactive metal suboxides have not been reported in published literature. However, data on the thermodynamic properties of metal suboxide vapors are being accumulated from a wide variety of sources.[5] These data have been used for estimating deoxidation tendencies of molten metal-oxygen systems. The results obtained experimentally correlate well with the theoretical values which were calculated by the following approach:

Using Brewer's[6] values for the heats of formation of the metal monoxide and dioxide vapors at 2000°K, and estimating the corresponding entropies of formation, the equilibrium constants for the reactions can be calculated. Since the vapor pressures of the metals are known, the assumption of an oxygen partial pressure permits the calculation of the equilibrium vapor pressure of the oxide and dioxides. If the oxygen activity (or vapor pressure) for the known titanium-oxygen system is used as the assumed value, the vapor pressures of the other metal oxygen systems can be calculated. It should be emphasized that this calculation is an attempt to relate an equilibrium vapor pressure to a highly non-equilibrium situation in a liquid, in order to estimate the rate at which the liquid would try to come to equilibrium with the vapor that is constantly being removed.

Table I summarizes the results of these calculations for a number of metal-oxygen systems. For convenience, the approximate ratios of the respective metal and metal-oxide vapor pressures are shown. Only the ratios involving the monoxides are included; the vapor pressures of the higher oxides were found in all cases listed to be of no relative importance. The left-hand column lists ratios greater than one, a criterion which indicates the tendency of the metals to lose oxygen by the monoxide vaporization mechanism. The right-hand column lists the metals that will not deoxidize by this mechanism.

Deoxidation in metal alloys

The mechanism of metal suboxide volatilization also may be applied usefully in estimating deoxidizing tendencies in metallic alloys. For example, the deoxidation of molybdenum is possible by the loss of TiO from an alloy of molybdenum and titanium. Complete vaporization of the titanium can be made to occur during the same melting operation. Samples of titanium-deoxidized molybdenum are sufficiently low in oxygen content that they will not fracture along grain boundaries, and conventional fractographs cannot be obtained.

Additional work is now in progress using this metallic deoxidation technique to produce molybdenum that is completely free of grain boundary precipitates. A subsequent program will then be pursued to evaluate the properties of ultra pure alloys of molybdenum of this quality.

The system columbium-zirconium was very useful in providing an understanding of the phenomena of deoxidation of mixtures of metals during electron-beam melting. An alloy consisting of columbium with 1 pct Zr lost 90 pct of the zirconium during electron-beam melting. The oxygen content of this alloy was initially about 0.15 to 0.20 wt pct and dropped to about 0.02 to 0.03 wt pct during electron-beam melting operations. According to the vapor pressure characteristics of the metals, the zirconium should not evaporate at a significant rate from an alloy. However, estimates of monoxide vapor pressures show that even at 0.1 pct Zr, ZrO is about ten times as volatile as CbO. The oxygen content of this metal stock was sufficient to account for the loss of about 0.9 pct Zr by this mechanism of monoxide evolution.

Accordingly, a second batch of alloys was prepared containing 2.0 pct Zr and the same oxygen content as before. Evaporation of the zirconium itself at a rate corresponding to its vapor pressure would bring the zirconium content down by about 0.2 pct. Loss of zirconium by the evaporation of its monoxide would reduce the content by about 0.9 pct. The result of the electron-beam melting was the production of columbium containing about 1 pct Zr. Therefore, the dominating mechanism for the loss of zirconium was the evolution of ZrO rather than the evaporation of zirconium.

The results of the deoxidation of columbium and molybdenum indicate a promising avenue of approach to the production of ultra pure tungsten and certain tungsten alloys. As an example, titanium and zirconium should be volatile deoxidants of tungsten, as titanium is of molybdenum; whereas columbium, tantalum, and hafnium should be nonvolatile deoxidants of tungsten.

The use of volatile deoxidants in metallurgy is by no means a new technique. However, the lower range of volatilities available for practical purposes in electron-beam melting allows the exploration of a whole new realm of deoxidation phenomena.

Melting columbium

Melting columbium by the electron-beam technique has reached the semi-commercial scale, i.e., tons of ingot product per month. Much of the general process development work was done in the course of achieving this level of production. As a result, considerably more data on the effects of electron-beam melting on the metallurgy of this material are available than for any other metal. It is, thus, appropriate to use columbium as an example in a detailed discussion illustrating the points noted earlier. Melting columbium also provides particularly interesting examples of the removal of such contaminants as oxygen, nitrogen, and carbon as well as the vaporization of many potentially desirable alloying elements. The information shown below is sufficient to indicate in a semi-quantitative way the chemical changes which occur, but uncertainties in analytical techniques are still large enough to prevent the presentation of a precise picture.

With respect to **evaporation of alloy metals** from columbium, present results show that vanadium and all other metals of greater volatility than vanadium evaporate rapidly to concentrations of

Table I. Sacrificial Deoxidation Tendencies of Metals (Shown by Ratio of Vapor Pressure of Metals & Monoxides)

Should Deoxidize		Should Not Deoxidize	
MoO / Mo	10^{-5}	TiO / Ti	1
CbO / Cb	10	VO / V	10^{-2}
BO / B	10^{2}	BeO / Be	10^{-3}
WO / W	10^{2}	CrO / Cr	10^{-4}
ZrO / Zr	10^{2}	MnO / Mn	10^{-5}
ThO / Th	10^{3}	FeO / Fe	10^{-6}
HfO / Hf	10^{4}	NiO / Ni	10^{-7}
TaO / Ta	10^{4}		
YO / Y	10^{5}		

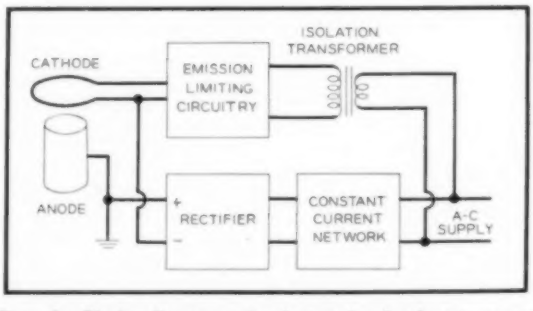


Fig. 4—Block diagram of electron-bombardment power supply.

less than a few hundredths of a percent by weight. These metals include iron, aluminum, nickel, and chromium. All metals less volatile than vanadium, such as zirconium, molybdenum, and tantalum, do not evaporate at appreciable rates from columbium-base alloys.

With respect to **removal of oxygen, nitrogen, and carbon,** the observed rates of purification do not correlate with data obtained in solid-state sintering in high vacuum. In electron-beam melting, loss of oxygen as CbO proceeds at a rate about four times faster than loss of oxygen as CO or loss of nitrogen as N_2. In solid-state purification, however, CO is the most volatile species, N_2 is the next most volatile, and CbO is the least. The reason for this anomaly is probably related to the relative chemical kinetics of the various species. In electron-beam melting, the rate-limiting mechanism in the loss of CO and N_2 is probably the diffusion of carbon, oxygen, and nitrogen in the liquid columbium in order to form the species that are also stable in the vapor phase. Evolution of CbO would not be limited by such a mechanism, since the oxygen atoms are essentially surrounded by columbium.

The specific rate of evolution of CbO from a melt is about 10^{-8} mols per sq cm of surface per sec, at a concentration level of about 1000 ppm by weight oxygen. Thus, electron-beam melting and casting of columbium at a rate of about 10 in. of ingot per hr drops the oxygen content from 2500 ppm to about 500 ppm. Remelting at the same rate lowers the oxygen content further to about 150 ppm. Within the limits of analytical uncertainties, rates of evaporation of species such as CbO appear to be proportional to concentration.

Removal of nitrogen to satisfactory levels requires either a lower melting rate than that for oxygen removal or lower initial concentrations of nitrogen in the melt stock. This is because of the fact (noted previously) that nitrogen removal is effected at a rate about one fourth that of oxygen removal.

A quantitative understanding of **carbon loss** as CO is presently impossible because of the competitive loss of oxygen as CbO. With initial oxygen:carbon ratios of at least five to one, however, and initial carbon concentrations of about 500 ppm, the carbon content of ingots melted and cast at a rate of 10 in. per hr is reduced to about 150 ppm.

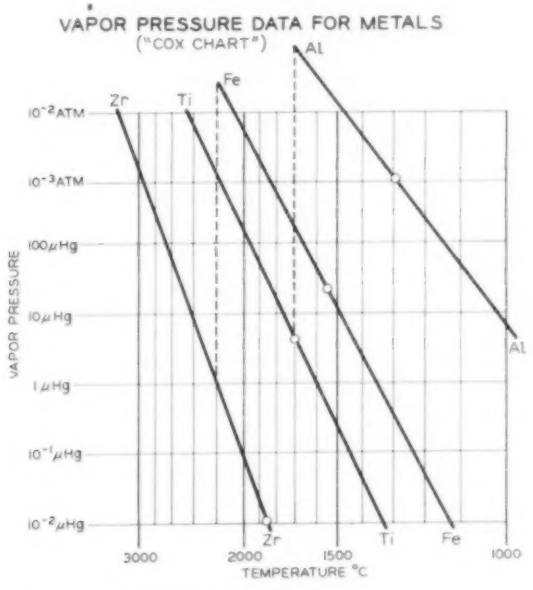


Fig. 5—Vapor pressure chart for metals.

An interesting comparison of devolatilization effects in solid-state sintering and electron-beam melting is shown most particularly in the **evaporation of iron** in both processes. Electron-beam melting of columbium reduces the iron content to levels of the order of 10 to 20 ppm, as would be expected from a consideration of the vapor pressures of the metals. However, in solid-state sintering, residual iron contents approximately ten times this level are obtained during purification cycles that reduce the oxygen and nitrogen contents to values as low as those obtained in electron-beam melting operations at commercial rates of production. Since both these operations are performed in high vacuum, there can be no influence of pressure upon the different rates, as is apparently the case in deoxidation phenomena in electron-beam melting compared to vacuum arc melting. The loss of iron in solid-state sintering is undoubtedly limited by the very low diffusion coefficient of iron in the solid columbium. In electron-beam melting, the intensively stirred molten pool brings the volatile iron to the surface rapidly.

In practice, it is necessary to control melting rates closely in order to produce columbium metal of given specifications from melt stock of known quality.

Summary

Electron-bombardment melting no longer need be regarded as a laboratory-scale technique. Results of melting materials by this technique cannot, in many cases, be duplicated by other means. Even at furnace throughput rates comparable to those of vacuum arc or vacuum induction melting, a higher degree of devolatilization of the melt occurs. These effects are due to the following unique combination of factors which constitute the electron-beam process:

1) The melt surface is exposed to high vacuum;
2) The melt is cast in a non-contaminating water-cooled mold;
3) The melt may be constantly observed visually;
4) The melt can be precisely controlled both with regard to residence time, material addition, and withdrawal and;
5) The melt can be held at any desired temperature—high superheats can be utilized to achieve reactions otherwise not possible.

The discussion has also included the preliminary theoretical efforts toward understanding the experimental observations. It is hoped that these preliminary data will stimulate comment, suggestions, and related study.

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PHOENIX-LANCE STEELMAKING

Here is an interesting new steelmaking technique being developed in Germany for the production of open-hearth quality steels from high-phosphorus pig irons. It utilizes the classical basic-bessemer converter with top-blown oxygen, and has the advantages of early phosphorus removal and, consequently, less nitrogen pick-up in the final steel.

by H. Th Brandi

At the Ruhrort plant of Phoenix-Rheinrohr AG in Germany, tests have led to the development of a new steelmaking process. This is the Phoenix-Lance, or the PL process, which is now ready for industrial application.

The new process, for which a patent application has already been filed, is conducted in the usual, basic-bessemer converter. The converter is not only bottom-blown in the upright position, but the blow is continued for a period with the converter tilted on its side, thus obtaining metal-slag reactions of the same kind as those occurring in the open-hearth furnace.

Operation of PL process

The operation of the PL process will be clear from the accompanying reaction curves for a blow, Fig. 1. In the first stage of the process, basic-bessemer pig is refined by bottom-blowing to a carbon content between 0.4 pct and about 0.1 pct. Then, for the second stage, the converter is tilted on its side, to act for a time as a kind of open-hearth furnace.

A water-cooled oxygen lance is now introduced into the mouth of the converter. By blowing *plant* oxygen, or pure oxygen, on the melt, the slag-formers are quickly melted down, obtaining, in addition to a slight degree of decarburization, a steady slagging-off of the phosphorus.

Finally, a brief raising of the converter and blowing with blast air and/or oxygen-boosted blast, lowers the phosphorus percentage within a few seconds to values of the order of 0.020 to 0.040 pct. It is generally possible simultaneously to control the carbon content of the steel bath within 0.02 to 0.10 pct, or higher values, if required. Naturally, by applying a secondary slag, the phosphorus content of the steel can be fairly easily brought down in essentially the usual manner to quite low levels. The final slag, i.e., the slag after the third process stage, corresponds to an ordinary basic slag, and can be credited with its full value as a fertilizer.

Since the PL process enables the dephosphorizing to be conducted in practically the same manner as in an open-hearth furnace, and the carbon percentages at the end of the actual refining blow are of the same order of magnitude as in the open-hearth process, the problems of nitrogen and oxygen elimination are practically solved. The nitrogen figures for PL steel are between 0.003 and 0.005 pct, while the oxygen percentages follow the carbon content of the refined, finished steel, as in the open-hearth or the LD process. Desulfurization

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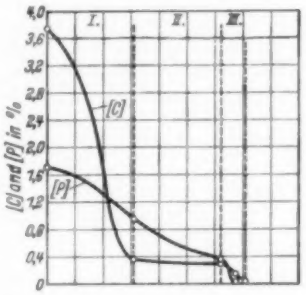

Fig. 1—Reaction curves for a blow using the Phoenix-Lance process.

is 70 to 80 pct, equaling that obtained in the buffer slag tests by Kosmider, Schenck, and others; the resulting advantages are obvious. Five PL heats had the following average analyses: 0.114 pct C, 0.298 pct Mn, 0.028 pct P, 0.014 pct S, and 0.004 pct N.

Total blowing time is about 15 min, or little longer than in the ordinary, basic-bessemer process. Oxygen consumption is about 2500 cu ft, of which over 50 pct is provided by atmospheric oxygen.

Importance of PL process

As already mentioned, the importance of the basic-bessemer process for Western Europe remains demonstrable, since there are still available supplies of high-phosphorus ores sufficient for many years.

The fact that the corresponding open-hearth steels with low copper and tin contents have to be made from pig-irons—hence from ores-particularly low in such undesirable metallic contaminations—is a considerable advantage of the present process.

From the point of view of the steelworks operator, the PL process affords substantial operating advantages. During a campaign, the blowing characteristics of a converter tend to change considerably. Furthermore, in a bessemer plant above all others, much depends on maintaining a suitable working rhythm, this applying equally to the sequence of heats, and to the relining of the converters and bottom replacements. It is immediately obvious that retaining the classical bessemer converter and using it for the production of steels equal to open-hearth quality, brings with it the considerable advantages of the fast-working rhythm and operational readiness of the converter plant.

These considerations have impelled Phoenix-Rheinrohr AG to contemplate the construction of an entirely new basic-bessemer steelworks of the classical type.

(At the Ruhrort plant of this firm, plans have been formulated for the construction of a new plant for the production of 6000 cu m per hr of 99.5 pct O_2 to supply converters being fitted with the Phoenix-Lance. **Ed.**)

BASIC BRICK IN COPPER CONVERTERS—Their Mineralogical Changes

Plant experience has shown that burned chrome-magnesite and burned magnesite brick give excellent service in copper converters. This study confirms that experience, but it also notes certain differences between the two.

C. Burton Clark and J. Spotts McDowell

Used chrome-magnesite and magnesite brick from copper converters were examined in connection with a broader study of refractories in the metallurgy of copper. While several practical articles on refractories used in copper smelting have been published,[1] very little has been reported in the literature on the mineralogical changes produced in the refractories during service.[2]

Pyrometallurgical treatment of copper ores or concentrates generally consists of three steps: roasting, smelting in the reverberatory furnace, and converting. The product of the converter is blister copper of 96 to 99 pct purity which is further refined by fire refining and electrolytic processes before final fabrication into articles of commerce.

Oxidation of the sulfur and iron and the formation of ferrous silicate supply the heat for the converter operation. The temperature is controlled by charging copper scrap, cold flux, or siliceous concentrates if the converter is too hot, and by charging molten matte if the temperature drops too low. Converters normally operate in the narrow range of 2100° to 2400°F. Low-temperature operation favors formation of magnetite, and build-up of a magnetite coating on the refractory lining; high-temperature operation prevents magnetite build-up, and consumes the refractory lining at accelerated rates. Many operators deliberately produce excess magnetite from time to time in order to coat the brick with a protective layer of magnetite. This practice will be discussed later.

Samples of burned chrome-magnesite brick and burned magnesite brick after service in copper converters were obtained from several plants. This report is confined to the examination of one brick of each of the two types.

Burned chrome-magnesite brick

The chrome-magnesite brick had been in service for a normal campaign in a Peirce-Smith converter. A cut section is shown in Fig. 1. The sample had a 4 x 4-in. cross section and was 4 in. long. It had spalled 1 to 1¼ in. back of the hot face, reportedly during the cooling of the converter as it was being taken out of service. The exposed face was coated with a thin, black slag which the cut section showed to be 1/16 in. thick. There were numerous small grains of copper to a depth of ½ in. and little apparent difference from there to the back end of the sample, which was an original brick surface. One side of the brick (which in service had been in contact with another brick) was coated with a ⅛ in. layer of copper and red cuprous oxide which had penetrated into the joint between the brick.

Burned magnesite brick

The magnesite brick selected for examination had been in service for a normal campaign in the tuyere section of a Peirce-Smith converter, but not in the same plant as the chrome-magnesite brick studied. A cut section is shown in Fig. 7. The sample was 4 x 4 in. in cross section and 7½ in. long. There was an ⅛ in. layer of cuprous sulfide on the exposed face and a dark discolored zone back to a depth of 2½ to 3¼ in. This area contained numerous thin bands of metallic copper which were roughly parallel to the exposed end. One prominent band occurred about 1½ in. back. The end of the dark zone was marked by a thin, red line of cuprous oxide, and the rest of the brick to the cold end was apparently unaffected. Bands of copper which had penetrated the joints between the brick were still present on the sides of the sample on the hot end.

Methods of study

The following tests were made on the various zones of the brick:

Chemical analysis,
Microscopic examination of polished surfaces by reflected light,
Microscopic examination of thin sections and powder mounts by transmitted light.
X-ray diffraction examination, and
Potassium cyanide spot test for distribution of sulfides.

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Table I. Chemical Analysis of Chrome-Magnesite Brick

Zone Number	1	2	3	3
Distance from Exposed End	Hot Face-1/16 In.	1/16 to ½ In.	3½ to 4 In.	3½ to 4 In.
Remarks	Slag Coating	Impregnated Zone	Cold End	Ignition Free Basis
Chemical Analysis, pct:				
Silica (SiO_2)	9.6	6.4	7.3	8.1
Alumina (Al_2O_3)	9.9	16.2	20.0	21.8
Total Iron as Ferric Oxide (Fe_2O_3)	53.5	11.3	10.1	11.0
as Magnetite (Fe_3O_4)		17.2	22.0	24.0
Chromic Oxide (Cr_2O_3)	8.6	0.8	0.9	1.0
Lime (CaO)	0.4	25.0	31.4	34.1
Magnesia (MgO)	8.4	0.02	0.02	0.02
Manganese Oxide (MnO)	0.02	20.7	0.0	0.0
Total Copper as Copper	7.7	0.2	0.0	0.0
Sulfur	0.9	0.6	8.2	0.0
Sulfur Trioxide (SO_3)	0.2			

I. CHROME-MAGNESITE BRICK

Results of the chemical analysis of the chrome-magnesite brick are shown in Table I. The sample for chemical analysis of Zone 1, the slag coating, was obtained by chipping off the thin layer of slag with a hammer and chisel. The coating was found to be high in silica and iron oxide, compared to the least affected end of the brick, Zone 3. It will be shown later that the coating was composed chiefly of magnetite, partially dissolved chrome spinel, and fayalite, ($2FeO \cdot SiO_2$). Microscopic examination showed that there was relatively little metallic copper, copper sulfide, or copper oxide in the slag coating, and there was a sharp line of demarcation between the coating and the brick. Therefore, the relatively high copper content of Zone 1 is believed to indicate that the sample analyzed contained some of the underlying brick material.

Test calculations showed Zone 2 to be composed of 75 pct chrome-magnesite brick material and 25 pct metallic copper with some magnetite. Microscopic examination of the zone indicated metallic copper had permeated the brick, filling the pores and consolidating the brick structure without appreciable chemical attack on the brick constituents.

The presence of a relatively large amount of sulfate in Zone 3, the cold end of the brick, was unexpected. The brick was wet-cut with a diamond saw quite a while before the chemical analysis sample was obtained by making a parallel cut with a saw operated dry. Chemical tests showed the sulfate in the chemical analysis sample to be chiefly soluble magnesium sulfate. Thus, the sulfate may have migrated to the surface in drying, in which case the value shown in Table I would be too high. Zone 3 has an analysis quite similar to a typical analysis for the brick before service except for the soluble sulfate.

Potassium cyanide spot test for distribution of copper sulfide

Tests were made for the localization of copper sulfides in the brick sections using the method developed by Yagoda.[3] Copper and silver sulfides which are etched by potassium cyanide can be localized in polished sections by contacting the polished surface with a lead cyanide emulsion moistened with potassium cyanide. Dark brown lead sulfide is precipitated forming mirror images of the copper and silver sulfide minerals. The tests showed the presence of sulfides in the magnetite coating but practically none in the brick.

Microscopic and X-ray examinations

Both polished sections and thin sections were prepared from the various zones of the brick and were examined microscopically. These zones, as well as selected areas, were studied by X-ray diffraction. Several powder mounts were examined microscopically by transmitted light as a further aid in mineral identification.

For the original presentation of this paper, three serial strips of color transparencies were made of a polished section which was cut perpendicular to the working face of the brick. They showed, at an original magnification of 80X, the microstructure from the exposed face back to a distance of ¾ in. into the brick. Representative photomicrographs of the area are recorded in Figs. 2, 4, and 5.

The magnetite coating on the working face of the brick is shown on the left side of Fig. 2. The black areas are voids, the darkest gray areas are the ferrous silicate mineral, fayalite, ($2FeO \cdot SiO_2$), while the intermediate gray grains are chrome grains from the brick. The smaller, lighter gray grains are impure magnetite. The magnetite (also a spinel) has crystallized onto the isomorphous chrome spinel grains, forming lighter gray borders around them. Several small, rounded grains of greenish-blue sulfide are scattered throughout the coating. These are believed to be a complex copper-iron sulfide, although the exact composition was not ascertained.

A very narrow interface between the magnetite coating and the brick cuts across the section at about the middle of the first large grain of metallic copper. An enlarged view of the interface is shown in Fig. 3.

Metallic copper has thoroughly permeated the brick structure in Zone 2, consolidating it and densifying it. The zone contains gray chrome spinel grains, dark gray forsterite and periclase, metallic copper, and cuprous oxide. In addition to the large copper grains with the small bluish-gray inclusions of cuprous oxide, there are innumerable, minute copper inclusions in the forsterite and periclase, giving them a reddish cast. The forsterite is dark gray and almost indistinguishable at the magnification of the photomicrograph in Fig. 2, but it is resolved quite well in Fig. 3. The borders of the chrome grains in the zone immediately below the slag coating are of a slightly lighter shade, indicating some reaction with iron oxide to give a spinel with a higher index. (With reflected light, the index of refraction of a mineral can be estimated from its shade of gray; the higher the index, the lighter the shade.)

Mineralogically, there has been little apparent change in the brick area represented in Figs. 4 and 5, except for the infiltration of copper and cuprous oxide and the densification noted above. This observation is strengthened by the results of chemical analysis which showed Zone 2 to be essentially 75 pct brick material and 25 pct copper and iron oxide.

There is an abrupt change from the metallic copper to cuprous oxide in Fig. 4, and only cuprous oxide occurs from there to the end of the penetrated area. Fig. 6 is a view from Zone 3, the cold end of the brick. It has the typical appearance of a photomicrograph of an unused chrome-magnesite brick.

An enlarged view of the interface between the magnetite coating and the brick is shown in Fig. 3. The magnetite coating is on the left side, and it consists of undissolved cores of chrome spinel grains

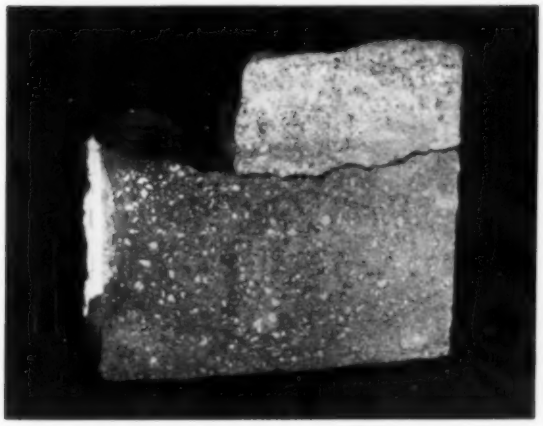

Fig. 1—Polished section of chrome-magnesite brick after normal campaign in a Peirce-Smith converter. Cut perpendicular to working face (upper right).

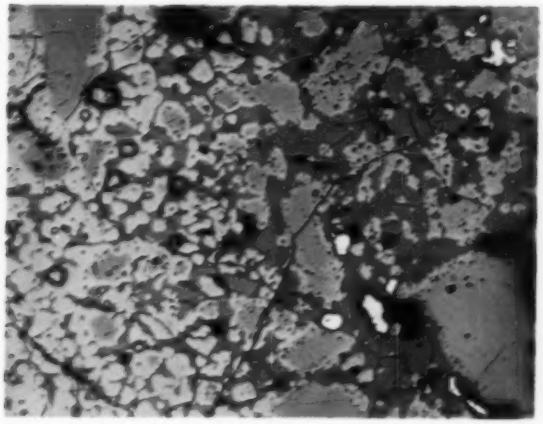

Fig. 2—Working face of chrome-magnesite brick. Reflected light, 80X. Left half is slag, and right half is brick. Reddish cast produced by finely disseminated copper (see text).

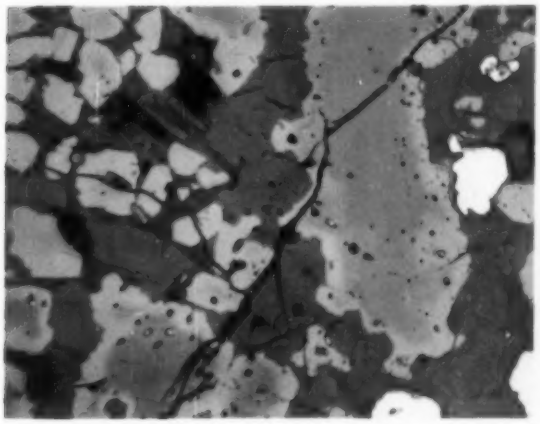

Fig. 3—Enlarged portion of Fig. 2 showing slag-brick interface, 250X. Medium gray chrome grains have light borders of isomorphous magnetite. Dark gray grains on left are fayalite in glass. Dark gray grains on right are forsterite impregnated with copper.

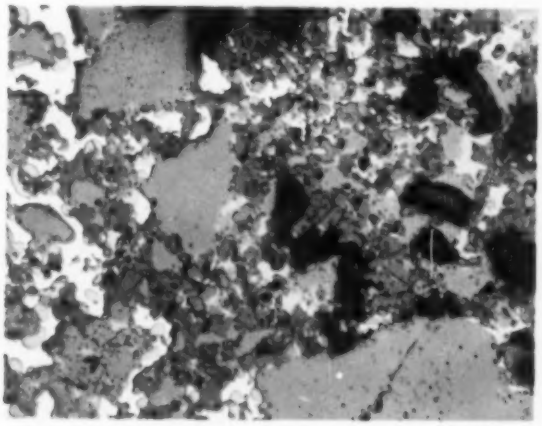

Fig. 4—Chrome-magnesite brick. Reflected light, 80X. Area ½ in. from working face showing change from metallic copper and cuprous oxide to bluish gray cuprous oxide only.

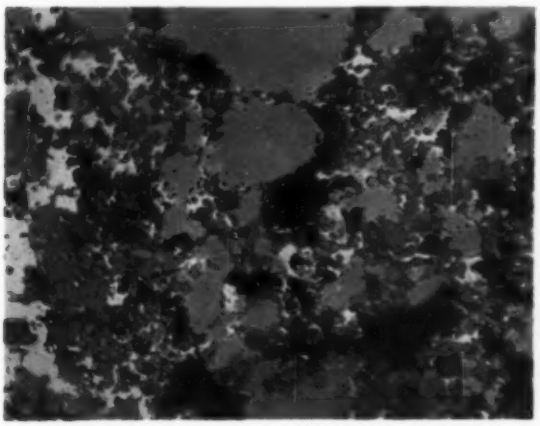

Fig. 5—Chrome-magnesite brick. Reflected light, 80X. Area ¾ in. from working face showing absorption of bluish gray cuprous oxide.

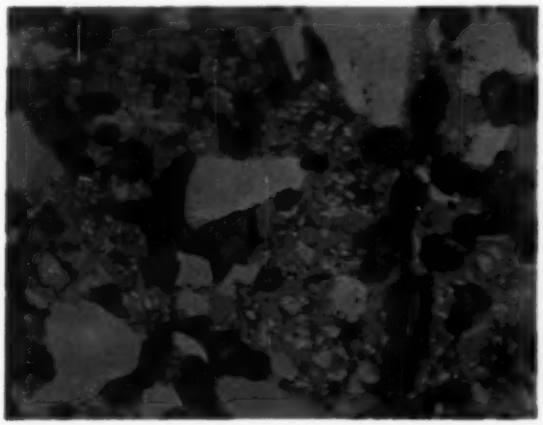

Fig. 6—Chrome-magnesite brick. Reflected light, 80X. Area in Zone 3. Light gray grains are chrome; matrix is mixture of silicate, periclase, and fine chrome. Black areas are voids.

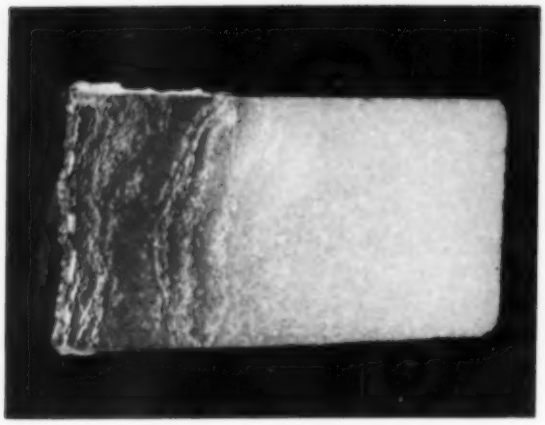

Fig. 7—Polished section of magnesite brick after normal campaign in tuyere section of Peirce-Smith converter. Cut perpendicular to working face (left side).

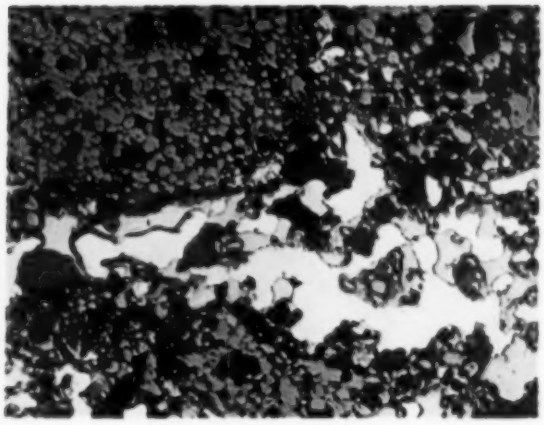

Fig. 9—Dark, penetrated area in Zone 2 of magnesite brick. Reflected light, 80X. Band of metallic copper and bluish gray cuprous sulfide runs through middle of dark magnesite grains.

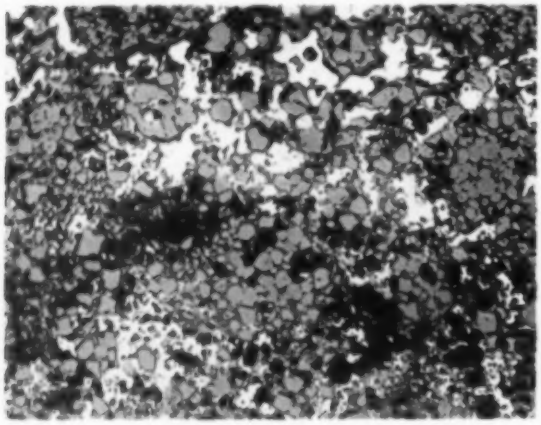

Fig. 10—Back end of dark, penetrated area in Zone 2 of magnesite brick. Reflected light, 80X. Copper and magnesite grains in upper half; bluish gray cuprous oxide and magnesite in lower. Black areas are voids.

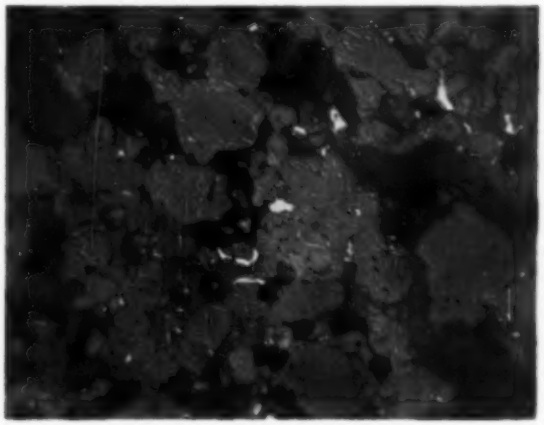

Fig. 12—Reddish zone at end of dark area in magnesite brick. Reflected light, 210X. Fine cuprous oxide imparts reddish color. Note gray inclusions along cubic directions in periclase.

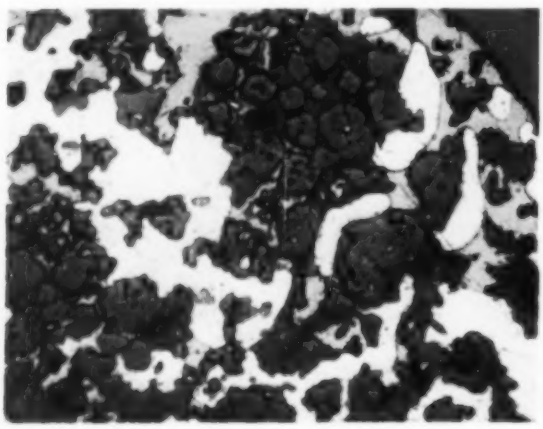

Fig. 13—Dark, penetrated area in Zone 2 of magnesite brick. Reflected light, 210X. Note copper beads in eroded periclase crystals. Bluish gray grains are cuprous sulfide.

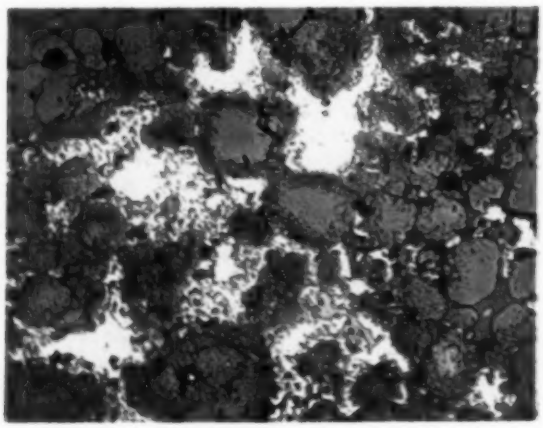

Fig. 14—Another area in dark, penetrated portion of magnesite brick. Reflected light, 210X. Note deeply etched borders on periclase crystals.

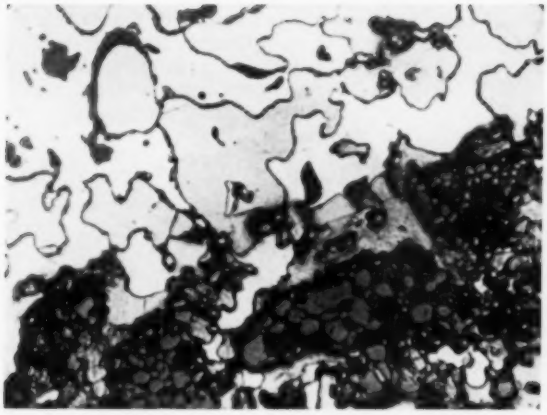

Fig. 8—Sulfide-brick interface of magnesite brick (left side of Fig. 7), showing metallic copper and cuprous sulfide in upper half, magnesite grains in the lower half. Reflected light, 80X. Reduced by 28 pct for reproduction.

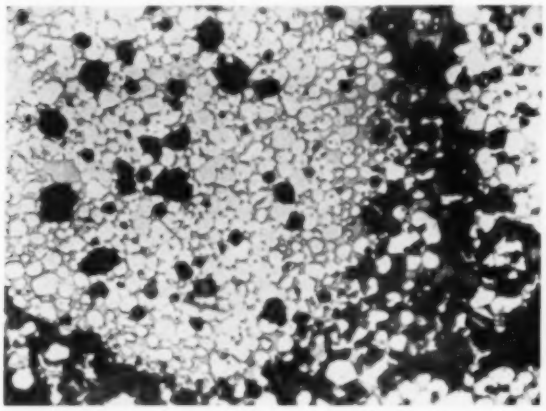

Fig. 11—Zone 3, the unaffected end of the magnesite brick, showing large rounded magnesite grains containing small, round periclase crystals cemented together with silicate. Black areas are voids. Reflected light, 80X. Reduced by 28 pct for reproduction.

with light gray magnetite borders, intermediate gray-colored fayalite and some dark gray glass. The large gray areas with the tiny red inclusions on the right side are forsterite crystals permeated with copper. The large grains of metallic copper are somewhat tarnished.

Fayalite is ferrous orthosilicate ($2FeO \cdot SiO_2$), and it is isomorphous with forsterite which is magnesium orthosilicate ($2MgO \cdot SiO_2$). The fayalite has crystallized onto the forsterite, forming a zoned structure in the same manner as the chrome spinel and magnetite. The reason for the presence of finely disseminated copper in the forsterite and its absence in the fayalite zone of the crystal is not known. However, the forsterite crystallized during the burning of the brick while the fayalite crystallized from a fluid melt under quite different circumstances.

II. MAGNESITE BRICK

Results of the chemical analysis of the magnesite brick are shown in Table II. Work had been outlined for the examination of this magnesite brick and several phases were well under way when evidence began to accumulate that the $\frac{1}{8}$-in. layer of dark material on the exposed end was chiefly sulfide and not a magnetite coating as presumed at first. The iron oxide contents of Zones 1 and 2 were found to be essentially the same as the iron content

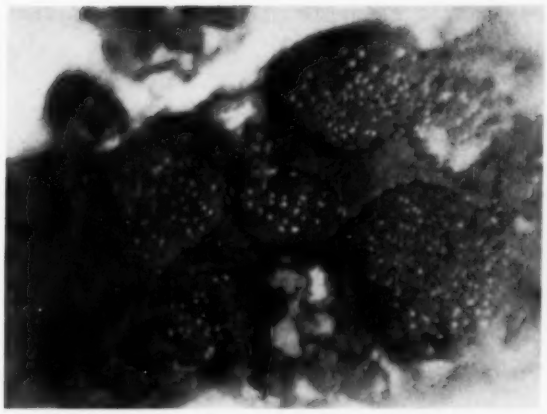

Fig. 15—Here, an island of magnesite is shown in a cuprous sulfide band. Rounded grains are periclase with inclusions, cemented with silicate. Blurred areas at the edge are cuprous sulfide. Reflected light, 345X. Reduced by 19 pct for reproduction.

Table II. Chemical Analysis of Magnesite Brick

Zone Number	1	2	3	3
Distance from Exposed End	Hot Face-$\frac{1}{8}$ In.	$\frac{1}{4}$ to $\frac{5}{8}$ In.	7 to 7½ In.	7 to 7½ In.
Remarks	Slag Coating	Impregnated Zone	Cold End	Ignition Free Basis
Chemical Analysis, pct:				
Silica (SiO_2)	0.9	3.7	4.2	4.4
Alumina (Al_2O_3)	0.3	0.9	0.9	1.0
Iron Oxide (Fe_2O_3)	1.6	1.6	1.9	2.0
Lime (CaO)	0.5	2.7	3.1	3.3
Magnesia (MgO)	15.4	70.8	85.0	89.2
Manganese Oxide (MnO)	0.1	0.1	0.1	0.1
Total Copper as Copper	63.1	13.8	0.0	0.0
Sulfur	15.3	1.9	0.0	0.0
Sulfur Trioxide (SO_3)	1.3	4.1	4.0	0.0

of the relatively unaffected cold end of the brick. The study was completed even though it was believed the working face of the brick was lost.

Test calculations showed Zone 1 to be composed of 17 pct magnesite brick material and 83 pct copper sulfide plus metallic copper. Similar calculations showed Zone 2 to be composed of 80 pct magnesite brick material and 20 pct metallic copper plus cuprous sulfide. Microscopic examination of Zone 2 indicated metallic copper and cuprous sulfide had permeated the brick, filling the pores and consolidating the brick structure as in Zone 2 of the chrome-magnesite brick.

Soluble sulfate was found by chemical tests to be present in all three of the zones analyzed. As with the chrome-magnesite sample, the magnesite brick was wet-cut first and later dry-cut for the chemical analysis sample. Migration of some soluble sulfate into the samples used for chemical analysis is a distinct possibility, and wet cutting would not have been used if the presence of soluble salts had been suspected.

Chemically, there did not appear to have been a selective solution of brick material in Zones 1 and 2 but rather an infiltration of metallic copper and cuprous sulfide into the microstructure of the brick.

Potassium cyanide spot test for distribution of copper sulfide

Yagoda's cyanide etch test showed much sulfide in the slag layer on the exposed face and in the dark, discolored areas of the brick. This contrasts sharply with the chrome-magnesite brick, where the sulfide was confined almost entirely to the slag coating.

Microscopic and X-ray examination

The sample was studied by means of (1) polished sections in reflected light, (2) thin sections and powder mounts by transmitted light, and (3) X-ray diffraction. Serial photomicrographs were not made but photomicrographs of representative areas were made. These are recorded in Figs. 8, 9, and 10.

The sulfide layer, Zone 1, was found to be composed chiefly of cuprous sulfide and scattered grains or globules of metallic copper. Near the sulfide-brick interface there was considerably more metallic copper than in the outer zone of the sulfide layer.

Zone 2 was found to be composed chiefly of dark colored magnesite grains, metallic copper, and cuprous sulfide as shown in Fig. 9. Both bands and discrete globules or beads of copper were scattered throughout the zone, while only the beads were found in the corresponding zone of the chrome-magnesite brick.

A narrow band of red cuprous oxide marked the end of the dark, discolored area, as shown in Fig. 10. Scattered grains of cupric oxide were also present. From this point to the cold end of the brick there were no apparent changes in the microstructure from that of an unused brick. Fig. 11 is a photomicrograph of Zone 3.

The periclase crystals in the magnesite grains in Zone 2 were dark greenish-blue to opaque in transmitted light. The mineral responsible for the discoloration was not ascertained. However, it is reported in the literature that up to 25 mol pct cupric oxide goes into solution in periclase.[4] Cuprous oxide is cubic in structure, and it also may form a solid solution with periclase. Magnesium sulfide is a third possibility, since it is cubic and has the same crystal space group as periclase. The Yagoda sulfide etch test showed a finely disseminated distribution of sulfide throughout the area, which indicated that the magnesite was thoroughly impregnated with sulfide.

The silicate matrix in the magnesite grains was found to be composed chiefly of monticellite ($CaO \cdot MgO \cdot SiO_2$) with some forsterite ($2MgO \cdot SiO_2$) in both Zones 2 and 3.

Certain areas of the dark, discolored zone contained periclase crystals which were deeply etched, particularly around their peripheries. This condition is believed to have had its origin in the red cuprous oxide band at the back end of the permeated zone, as shown in Fig. 12. The light gray lines in the periclase crystals are a copper compound, filling cracks between cleavage planes in the periclase. Unresolved cuprous oxide permeates the area, giving a reddish tint to the photomicrograph. The prevailing temperature in this area is believed to have been relatively low.

Fig. 13 is a photomicrograph of a copper-impregnated area inside the dark, discolored zone about ½ in. toward the exposed face. Small beads of copper are present in many of the etched pits in the periclase crystals. Fig. 14 is a photomicrograph of an area in about the middle of the dark, discolored zone. The rounded pits in the periclase indicate appreciable rearrangement within the periclase crystals. Fig. 15 is a photomicrograph of a small island of brick material in the sulfide layer on the exposed end of the brick. The difference in hardness produced too much relief in the polished area for both the bluish-gray cuprous sulfide and the much harder magnesite grain to be in focus at a magnification of 345X.

It is believed Figs. 12 to 15 show the various stages of the deep etching or pitting of the periclase crystals in the dark, discolored zone. Self healing of the periclase apparently occurs at the higher temperatures toward the hot face and the phenomenon is believed not to be particularly damaging to the service of the magnesite brick.

III. DISCUSSION

The results of chemical analysis and mineralogical examination of the magnesite brick strongly indicated that the working face had been lost. However, the results which were obtained indicated that the brick wore away during service more from mechanical failure than from chemical attack. Metallic copper has a coefficient of thermal expansion equal to 16.7×10^{-6} compared to 12.6×10^{-6} for a magnesite brick. Repeated freezing and melting of the copper stringers during cooling and heating of the copper would be expected to weaken the structure of the brick.

The absence of copper stringers in the chrome-magnesite brick is believed to be significant, as the finely disseminated copper beads in the area immediately below the slag coating would not be nearly as damaging to the mechanical strength of the brick as the stringers.

A thick magnetite coating would be expected to be beneficial, as it would tend to reduce the top temperature of the working face of the brick. Fayalite is molten above 2215°F, and the top operating temperatures of copper converters are reported to be in the range of 2100° to 2400°F. Thus, with no coating or with a relatively thin coating, the working face of the brick would be subjected to an erosive liquid when the converter was operated above 2215°F.

Plant experience has shown that burned chrome-magnesite and burned magnesite brick give excellent service in copper converters. This study confirms that experience, since it shows that chemically and mineralogically both are well suited for service in copper converters. However, certain differences were noted; for example, sulfides were found throughout the dark, penetrated zone of the magnesite brick but none of any consequence beyond the slag coating on the chrome-magnesite brick. Also, copper and copper sulfides were distributed throughout the penetrated zone of the magnesite brick, while copper and cuprous oxide were present in the chrome-magnesite below the working face and then only cuprous oxide in the cooler areas of the penetrated zone. The full significance of these differences was not ascertained.

It is planned to continue the broad investigation of refractories used in the metallurgy of copper, as mentioned at the beginning of this paper.

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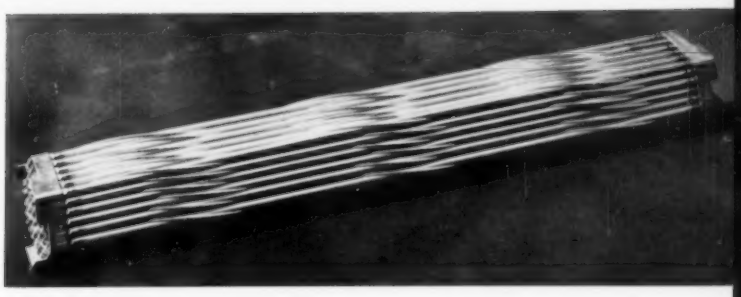

PLUTONIUM

This member of the Transuranium group, found as a fission product of U-235, may well hold the key to economic nuclear power.

by Bernhard Blumenthal

ON Jan. 28, 1941, G. T. Seaborg, E. M. McMillan, J. W. Kennedy, and A. C. Wahl submitted a paper to the *Physical Review* for publication, wherein they reported that they had bombarded uranium oxide, U_3O_8, with 16 mev deuterons in the 60 in. Berkeley cyclotron.[1] This action had produced an isotope of element 93 with a two day half-life, which decayed to an alpha particle emitting an isotope which, they claimed, might be an isotope of element 94. They were able to precipitate the new radioactive element as a fluoride, an iodate, and a peroxyhydrate. Subsequent work confirmed the existence of the new element with the atomic number 94.

Actual publication of this and other papers was voluntarily withheld at that time and did not take place before 1946, for obvious security reasons. Following McMillan, who had named element 93 neptunium, after Neptune, the first planet beyond Uranus, the new element was named plutonium, after Pluto, the second planet beyond Uranus.

This was the beginning of the story of the new metal, plutonium. Its first phase ended when, on July 15, 1945, C. S. Smith placed a plutonium core in the subassembly of the first atomic bomb in McDonald's farmhouse, located on the test site of Alamogordo.[2] Seventeen hours later the first nuclear explosion took place.

The properties of plutonium were not made public before 1954. At the Geneva Conference on the Peaceful Uses of Atomic Energy, in 1955, more information on this new and interesting metal was released. It is now possible to relate many of the properties of the metal that has contributed so much to our world today.

The actual birth date of plutonium was in 1943 when, between the 6th and the 9th day of November, H. L. Baumbach made the first unequivocal reduction of plutonium metal on a microgram scale at the Metallurgical Laboratory in Chicago.[3] During the following months, work on plutonium progressed on the micro- and milligram scale. In the meantime, Los Alamos Scientific Laboratory was built up, and in April 1944, R. D. Baker produced plutonium for the first time on a gram scale.[4] At first, scientific information on the properties of plutonium was obtained only to the extent that was necessary to satisfy immediate needs. Since 1945, metallurgists at Los Alamos, under the direction of E. Jette, have studied the metal and its alloys more thoroughly and have built up a much firmer body of knowledge.[5]

Today plutonium is produced in this country in the big plants at Hanford, Wash., and Savannah River, Ga. The Hanford plant is operated for the AEC by the General Electric Co.; the Savannah River plant is run by E. I. du Pont de Nemours Inc. Research on plutonium is carried out both at the Los Alamos Scientific Laboratory, operated by the University of California, and at Argonne National Laboratory, operated by the University of Chicago.

Plutonium research is carried out in Great Britain at the Harwell research center, and the Atomic Weapons Research Establishment in Aldermaston. Britain's plutonium production facilities are located in Windscale and Calder Hall. In France plutonium research is carried out at the Centre d'Etudes Nucléaires de Fontenay-aux-Roses near Paris. Russia's contribution to both Geneva Conferences showed that she has done a good deal of work on the metal and has obtained much valuable and accurate information.

Peaceful applications

While most all the early plutonium work was motivated by its applicability to weapons, major emphasis is now placed on the use of the metal as a nuclear fuel. Argonne's plutonium research facility is devoted exclusively to basic research and to the development of plutonium-bearing fuel elements. It is anticipated that the Experimental Breeder Reactor II, designed at Argonne, will have a core of plutonium-bearing fuel elements in the later loadings. These elements will be fabricated at Argonne in a fuel fabrication facility which will come into operation in 1959.

Fuel cycles

The only naturally occurring fissionable material is U-235. All the presently operating reactors consume this material, and with the rapidly increasing

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number of reactors in operation, one might conceive of the time when substantial portions of the present and future U-235 supply will be exhausted. The possibility of burning U-235 and making the same amount of another fissile material, i.e., plutonium, has been recognized by W. H. Zinn[5]—this process is called breeding. It is based on the fundamental reactions that occur in a chain-reacting pile: U-235 captures a neutron, fissions, and produces fission products, more neutrons, and 200 mev of energy. Thus:

$$\text{U-235} + n \rightarrow \text{fission products} + 2.5n + 200 \text{ mev}.$$

Those excess neutrons, which are neither used for the continuation of the chain reaction nor are lost by leakage from the pile, are captured by U-238 forming U-239, which decays by beta emission to Np-239, which in turn decays by beta emission to Pu-239. Thus:

$$\text{U-238} \xrightarrow{n,\gamma} \text{U-239} \xrightarrow[23.5min]{\beta^-}$$

$$\text{Np-239} \xrightarrow[2.33days]{\beta^-} \text{Pu-239}.$$

Plutonium-239, an alpha emitter, has a half-life of 24,300 years and is, in itself, a fissile material. After separation from the uranium and the fission products, it can be placed in a reactor replacing U-235 and producing neutrons. Thus:

$$\text{Pu 239} + n \rightarrow \text{fission products} + 2.9n + 200 \text{ mev}.$$

The interaction of these neutrons with more U-238 will produce more plutonium so that eventually the U-238—Pu-239 cycle will be self contained. There exists another breeding cycle based on Th-232 that produces U-233.

$$\text{Th-232} \xrightarrow{n,\gamma} \text{Th-233} \xrightarrow[23.3min]{\beta^-}$$

$$\text{Pa-233} \xrightarrow[27.4days]{\beta^-} \text{U-233}.$$

For an evaluation of this cycle, see the Geneva Conference paper by A. M. Weinberg.[7]

Recovery of plutonium

Plutonium was the first of the transuranium elements that was man-made on a large scale. The element is not obtained from ore deposits as are other metals, and a search for plutonium in nature showed that no economic deposits can be expected to exist, as shown in Table I.[8,9]

The first step in the recovery and preparation of plutonium metal is its chemical separation from the unreacted uranium in the fuel element, from the cladding material with which the core of the fuel element is protected, and from the fission products which have formed simultaneously with the formation of plutonium. These fission products are highly radioactive and necessitate remote operation of the entire process. It is advisable to cool the fuel element for a 100-day period for two reasons: this allows the intense radioactivity to decrease, and the plutonium to complete its formation. The fission products from which the plutonium must be separated are shown by the fission yield curve, Fig. 1. In order to permit handling of the recovered uranium in the open by ordinary techniques, it is necessary to decontaminate the metal by a factor of the order of 10^7.

In general, the principles of plutonium recovery follow fairly closely the processes developed for uranium. For example, the metal may first go through a solvent extraction process. The aqueous nitric acid solution of plutonium, uranium, and fission products is contacted with an organic solvent which is immiscible in the aqueous solution. Extraction depends on the oxidation state of the plutonium ion. An example is shown in Table II.

If uranium is kept in the hexavalent state (VI) and plutonium in the tetravalent state (IV), both are extracted together and separated from the fission products. By keeping uranium and plutonium at different oxidation states, uranium at VI, plutonium at III, a good separation of plutonium from uranium can be effected. By repeating the process under a variety of conditions, an excellent decontamination is achieved, resulting in a pure product. This product is $PuO_2(NO_3)_2$, plutonylnitrate. From this point on, the process for making plutonium is similar to that for uranium, except that criticality hazards severely limit the quantities of plutonium that may be handled in one batch. The critical mass is of the order of a very few pounds, and depends largely on the geometry of the particular material and the presence of a moderator. In each case it has to be specifically evaluated.[10]

In general, the plutonylnitrate is ignited in air to give PuO_2, plutonium dioxide, the most stable of the plutonium oxides. The oxide is converted to plutonium fluoride by direct hydrofluorination:

$$PuO_2 + 4HF \rightarrow PuF_4 + 2H_2O.$$

The plutonium fluoride is mixed with calcium metal, placed in a closed steel bomb—which is lined with a refractory material—and heated to initiate the exothermic reaction:

$$PuF_4 + 2Ca \rightarrow Pu + 2CaF_2.$$

The resultant metal is collected at the bottom of the bomb and easily separated from the salt layer above.

Toxicity of plutonium

The metal plutonium is a mixture of several isotopes, of which the fissile Pu-239 is the most important. The isotopes Pu-238, 239, 240, and 241 are

Table I. Plutonium Content of Uranium and Thorium Ores

Ore	Uranium Content, Pct	Ratio Pu^{239}/Ore, by Wt	Ratio Pu^{239}/U-10[12]
Canadian Pitchblende	13.5	9.1×10^{-13}	7.1
Belgian Congo Pitchblende	36	4.8×10^{-12}	12
Colorado Pitchblende	50	3.8×10^{-12}	7.7
Belgian Congo Pitchblende Concentrate	45.3	7.0×10^{-12}	15
Brazilian Monazite	0.24	2.1×10^{-14}	8.3
North Carolina Monazite	1.64	5.9×10^{-14}	3.6
Fergusonite	0.25	$<1\times10^{-14}$	<4
Carnotite	10	$<4\times10^{-14}$	<0.4

Table II. Distribution Ratio, E_{aq}^{org}, for Plutonium Extraction Into Tributyl Phosphate; 20 Pct Solution in Kerosene[12]

Aqueous Composition	Pu(III)	Pu(IV)	Pu(VI)
1 *m* HNO_3	0.01	1.5	0.7
3 *m* HNO_3	—	6.8	2.26
6 *m* HNO_3	0.01	19.6	2.86
10 *m* HNO_3	—	13	2.27
1 *m* HNO_3, 3 *m* $NaNO_3$	—	19.0	—
1 *m* HNO_3, 5 *m* $NaNO_3$	—	62	—

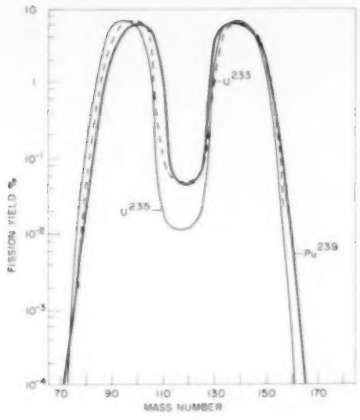


Fig. 1—Fission yield for plutonium in a thermal neutron flux of given mass number.

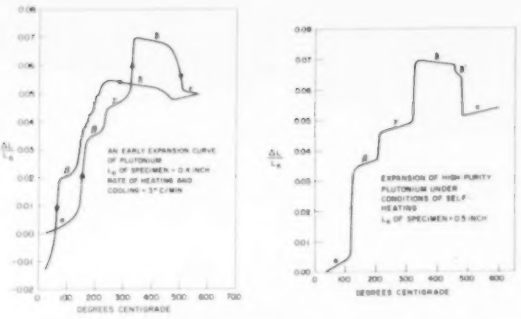


Fig. 3—Expansion curve for plutonium. At left, an early curve from Los Alamos; at the right is a recent curve for high-purity plutonium under self-heating conditions.

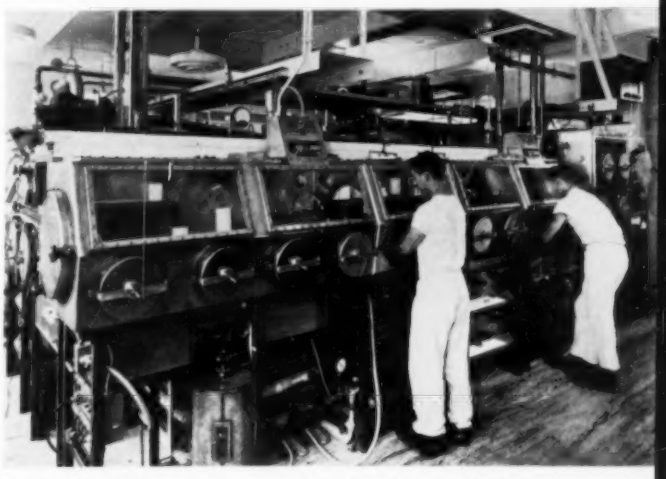


Fig. 2—Plutonium metallurgy research lab at Argonne National Laboratory.

most abundant.[12] Comparison of the half-life of Pu-239 with that of U-235, Table III, shows that plutonium is about 30,000 times more radioactive than U-235 and, therefore, must be handled with much greater care than the uranium isotopes 238 and 235. Although the alpha particles of plutonium have little penetrating power (3.68 cm in air and about 45μ in body tissues), they do cause severe damage in body tissue surrounding it.[13] If plutonium should enter the body, some amount will be retained in the bones and secreted very slowly. Therefore, it is most important that plutonium be handled in such a manner that under no circumstances allow it to enter the human body. The total permissible burden in a man's life is 0.6μ-gm.

The toxicity problem is aggravated by the chemical properties of the metal, which oxidizes very rapidly, sometimes to very fine particles. In this form it is easily carried into the surrounding atmosphere. In finely divided form, plutonium metal is highly pyrophoric. If it ignites, contamination can easily spread. The properties of plutonium make it mandatory that it be handled in closed, air-tight, and fireproof containers (called gloveboxes), which are kept at a slightly negative pressure against the surroundings. With such precautions, plutonium is handled without undue risk. Fig. 2 shows a view of the plutonium research facilities at Argonne. The system has a helium atmosphere; the pressure maintained in the boxes is about -0.5 in. of water column. In this system metallurgical operations are carried out in safety, as shown by a satisfactory safety record during more than 4 yr of operation. The system is equipped to handle metallographic work, mechanical testing, melting in a variety of electrical furnaces, rolling, drawing, machining, and other operations. Physical properties, such as density, electrical resistivity, thermal expansion, and thermal conductivity, can be determined. For a staff of six scientists, six technicians, two machinists, and a radiological physicist, the facilities are rather crowded, but a new Nuclear Fuels Technology Center is being built at Argonne where the plutonium research facilities will be expanded tenfold.

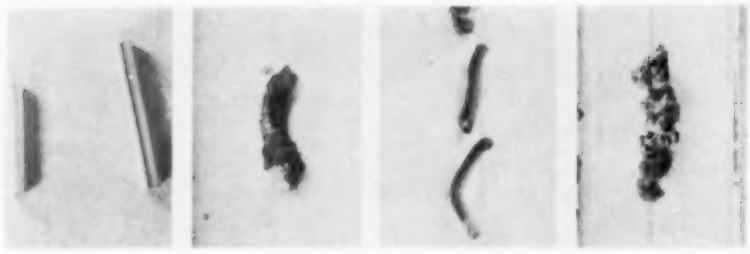
Table III. Half-Lives of Uranium, Plutonium, and Thorium Isotopes

Isotope	Half-Life in Years
U-233	1.62×10^5
U-235	7.07×10^8
U-238	4.5×10^9
Pu-239	2.436×10^4
Th-232	1.39×10^{10}

Properties of plutonium[13]

Plutonium has a low melting point, 640°C, comparable to that of aluminum and magnesium. Its vapor pressure is so low that its boiling point of 3300°C compares with that of uranium. Plutonium is distinguished from all other metals in that it occurs in no less than six allotropic modifications, Table IV. The crystal structures of these six modifications are listed in Table V. Its room-temperature density is higher than that of uranium. The most interesting properties of plutonium are the dilatometric changes that occur when the metal is heated into the delta and delta-prime phase. Even though the delta phase has a face-centered cubic crystal structure and should expand on heating like other face-centered cubic metals, plutonium contracts on heating. The phenomenon is greatly affected by the purity of the metal, and only after Los Alamos had produced a sufficiently pure metal was it possible to confirm the effect. An early expansion curve is shown in Fig. 3 along with an expansion curve of high-purity plutonium.

The low melting point of the metal, the volume changes on heating and cooling, the negative coefficients of expansion of the delta and delta-prime phases, the rate of oxidation of the metal, and its poor corrosion resistance make it impossible to use the solid pure metal as a core material for fuel ele-



	A	B	C	D
Burnup, pct	0.92	0.84	0.43	0.42
Central metal temperature, °C	310	430	490	480

Fig. 4—Typical irradiation results on uranium-plutonium base alloys: A, U-20 wt pct Pu-10.8 wt pct Fs, cast; B, U-13 wt pct Pu, cast; C, U-14.1 wt pct Pu, extruded; D, U-14.1 wt pct Pu, extruded and heat treated. 2X.

ments. The only way to use solid plutonium as a nuclear fuel is by alloying it with other metals. Such an alloy is presently considered as the fuel for the Experimental Breeder Reactor II (EBR-II).[14]

Experimental Breeder Reactor II

The EBR-II is a large engineering facility designed to obtain information which will permit scaling up to a commercial-sized power station, economically competitive with conventional power stations.[15] It will be the successor to Argonne's EBR-I, which was an experimental facility designed to study the possibility of breeding in a fast reactor.

The EBR-II will contain 637 fuel element subassemblies. All subassemblies are identical in size and are distributed as follows:

Core	47
Safety	2
Control	12
Inner blanket	66
Outer blanket	510
	637

Each of the core subassemblies consists of 91 fuel pins. The fuel pin is made from a stainless steel tube of 0.172 in. OD and 0.009 in. wall, into which is inserted the actual fuel in the form of a pin of 0.144 in. diam, 14.22 in. length. The resulting 0.006 in. annulus is filled with sodium to transfer the heat from the fuel pin to the tube. A circular wire is wound helically around the external surface of the tube to provide rigid spacing of the fuel pins. Heat generated in the fuel pins is removed by sodium that is circulated between the pins. The entire reactor assembly, consisting of core, blanket, and control rods, is placed in the primary reactor tank which is approximately 6 ft in diam and 6 ft high.

The primary tank contains the various operating mechanisms, such as the control and safety rod drive systems, and is filled with sodium. The reactor is housed in a large-domed cylindrical steel and concrete shell of 80 ft diam and about 140 ft height. The process plant and the power plant convert 62,500 kw of heat to 20,000 kw of electricity.

A plutonium fuel alloy

Since pure plutonium is not a suitable fuel element material, it is necessary to use an alloy which will permit a high degree of utilization of the fuel, produce a high specific power, and have a high degree of stability at high temperature and radiation levels.[16] An alloy consisting of uranium and 20 wt pct Pu was chosen mainly because of extensive experience with uranium base alloys and because U-238 is a fertile isotope from which plutonium can be obtained by breeding in the core itself. At a high specific power level, it will be necessary to recycle the fuel quite frequently even if a 2 pct burnup per cycle is to be achieved. At this burnup, rapid replacement of the spent fuel is necessary. Speed in recycling of the fuel is economically important to keep the inventory of the valuable fissionable fuel low. The present aqueous processing methods, similar to those employed for the original recovery of plutonium from thermal reactor fuel elements, require a long cooling period which builds up a large inventory. Therefore, it was desirable to have a process for the recovery of nuclear fuel that left the metal in its metallic state rather than dissolution of it in acid followed by the entire purification and reduction process.

The process is a simple pyrometallurgical operation, consisting of melting the fuel in an oxide crucible. The gaseous fission products and cesium are volatilized, and the rare and alkaline earth elements

Table IV. Phase Transformation Temperatures of Plutonium on Heating, °C.

	Jette, 1955		Ball et al., 1954		Konobeevsky, 1955
Transition	Dilatometry	Thermal Analysis	Dilatometry	Thermal Analysis	Dilatometry and Thermal Analysis
α to β	122±2	122	135	125	119
β to γ	206±3	203	225	235	218
γ to δ	319±5	317	315	325	310
δ to δ'	451±4	453	450	450	450
δ' to ϵ	480±7	478	480	475	472
ϵ to liquid	—	639.5±2	—	640	640

Table V. Crystal Structure Data for the Plutonium Phases

Phase	Crystal Lattice	Unit Cell Dimensions, A	Number of Atoms in Unit Cell	Calculated Density, Gm per Cu Cm
Alpha	Monoclinic	At 21°C: $a = 6.1835 \pm 0.0005$, $b = 4.8244 \pm 0.0005$, $c = 10.973 \pm 0.001$, $\beta = 101.81° \pm 0.02°$	16	19.816±0.006
Beta	Crystal structure unknown		—	—
Gamma	Face-centered orthorhombic	At 235°C: $a = 3.1587 \pm 0.0004$, $b = 5.7682 \pm 0.0004$, $c = 10.162 \pm 0.002$	8	17.14 ±0.01
Delta	Face-centered cubic	At 320°C: $a = 4.6371 \pm 0.0004$	4	15.92
Delta-prime	Body-centered tetragonal	At 465°C: $a = 3.327 \pm 0.003$, $c = 4.482 \pm 0.007$	2	16.00
Epsilon	Body-centered cubic	At 490°C: $a = 3.6361 \pm 0.0004$	2	16.51

are preferentially oxidized. However, not all of the fission products are removed by this simple melting operation. The remaining elements are zirconium, molybdenum, technicium, ruthenium, rhodium, and palladium, and in proper proportion are called fissium. After several cycles, an equilibrium concentration of uranium, plutonium, and fissium will have been reached. The actual composition of this alloy may vary,[15] but a nominal composition is:

U, pct	69.0
Pu, pct	20.0
Zr, pct	0.5
Mo, pct	4.0
Ru, pct	4.0
Rh, pct	1.0
Pd, pct	1.5

It is fortunate that these uranium-plutonium-fissium alloys have quite desirable properties and seem to be dimensionally stable under irradiation—yet they are still radioactive. While the oxidation melting process removes most of the beta activities from the metal, the fissium elements still carry a very high gamma activity with them, so that the processing must be performed by remote control behind a thick shield.

Some of the irradiation results that were obtained with uranium-plutonium and uranium-plutonium-fissium alloys are shown in Fig. 4. Improvement by the addition of fissium is substantial.

Fuel pin fabrication

The refabrication of the partially decontaminated metal into new fuel pins is done by a new process devised by A. B. Shuck of Argonne,[17] where the metal is melted in a vacuum furnace. A cluster of Pyrex glass tubes is suspended over the melt. These tubes are closed at the upper end but open at the lower end. When the alloy is molten, the crucible is raised so that the open tube ends dip into the metal. Helium or argon gas is then permitted to enter the furnace and push the molten metal into the evacuated tubes. After cooling and breaking the glass tubes away from the casting, a pin is obtained which can be immediately cut to the proper length and inserted into the sodium-filled stainless steel tubes which were described previously. Thus, the entire fuel cycle consists of only two basic operations: the pyrometallurgical refining operation, which restores the alloy to its equilibrium composition, and the casting process which fabricates the alloy into fuel pins. It is believed that this combination of refining and casting processes will satisfy the requirement of an economical fuel cycle.

Taking into account all considerations, F. G. Foote believes that we have arrived at a plutonium fuel element composition and design which simultaneously satisfies the requirements of nuclear physics, reactor performance, pyrometallurgical refining, and metallurgical refabrication.[16]

Other plutonium applications

Other organizations besides Argonne have considered the use of plutonium in nuclear reactors. The Los Alamos Scientific Laboratory is working on the LAMPRE project, the Los Alamos Molten Plutonium Reactor experiment. This reactor makes use of a molten plutonium-iron eutectic alloy containing 9.5 pct Fe and melting at 410°C. The alloy is contained in tantalum tubes and the reactor is cooled with sodium. This reactor is still in an early stage of development.

The use of UO_2-PuO_2 ceramic fuel has been proposed by Knolls Atomic Power Laboratory. This fuel element seems to be suited for high burnups, and the dilution with oxygen does not appear to affect the breeding ratio too seriously.

A full-scale fast reactor power plant for the production of 100,000 kw of power is planned at Monroe, Mich., by the Power Reactor Development Corp. Although this plant's reactor will be loaded first with U-235 fuel elements, it is being designed for later operation using plutonium.

The same idea seems to apply to the Dounreay Reactor built in Scotland. Other experiments with plutonium have been made in Los Alamos in their fast reactor experiment and at Chalk River, Canada, where considerable reactor experience with plutonium-aluminum alloys has been gained. Aluminum-plutonium alloys were irradiated in the MTR for the determination of the irradiation stability of such alloys and the isolation of significant amounts of elements 99 and 100.

This is the present status of plutonium metallurgy. We still lack much basic information in the alloy field which would enable us to predict with greater certainty the behavior of these alloys under irradiation. Data on the structure of alloys, the many physical and mechanical properties of these alloys, their behavior in liquid metal, their response to heat treatment, and many other data have to be obtained in day-to-day research to enable the reactor engineer to build the safe and economical power plant of the future. The equipment that is necessary to handle the hazardous material is quite complex and still requires considerable development work. Also, the transuranium elements, with their complex structure, offer a challenge to the scientists who are interested in fundamental research on metals and their alloys. I believe that all this work will eventually lead to the use of plutonium for the production of electrical power on a significant scale, meaning that swords are indeed beaten into plowshares.

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EFFECT AND CONTROL OF IMPURITIES IN THE ELECTROWINNING OF ZINC

Most of the elements known can appear as impurities in zinc concentrates. This article presents a survey of those which are likely to cause trouble in electrolytic zinc plants.

Summarized from an article

by G. T. Wever

Zinc is marketed in several grades, ranging from Prime Western, the lowest, to Special High Grade, the highest, with a purity of 99.99+ pct. Electrolytic zinc holds its position in the market by producing a pure zinc; this it must do to compete with other less complex methods.

Briefly, the recovery of zinc by the electrolytic method may be divided into five categories: 1) mining and concentrating, 2) roasting, 3) leaching and purifying, 4) electrolysis, and 5) casting zinc metal into shapes for market.

All electrolytic zinc plants follow the same general procedure, but no two plants employ exactly the same methods. The reason for this is that most of them were originally developed to operate on ores from one particular source, and zinc ores vary widely in the amount and kind of elements occuring with the zinc. Later, plants began reaching out farther and farther for their raw material, and those using the electrolytic process found it necessary to alter their methods to meet the changing conditions as new and different impurity elements were encountered.

Zinc in the concentrates is largely in the form of the sulfide, which is insoluble in dilute sulfuric acid. It is converted into soluble zinc oxide by roasting. A small amount of water-soluble zinc sulfate may also be formed. A controlled amount of sulfate is desirable in order to balance the loss of sulfate ions in the residues from the system.

The leaching and purifying steps, which may take place simultaneously, are the most intricate and involved in the entire process. Roasted concentrates are dissolved with dilute sulfuric acid to produce a solution containing the desired amount of zinc sulfate. This solution is purified to remove or control undesirable or harmful impurities; it is then used as a feed to the electrolyzing step.

Electrolysis of the purified solution is the most critical step of the process, for the electrolyzing cell will react to impurities in amounts not readily detectable by ordinary means.

Electrolytic zinc is recovered on a commercial scale by plating zinc from an electrolyte in cells which use insoluble electrodes. Anodes are made from lead or lead alloys, while cathodes are sheets of high-purity aluminum. The electrolyte is a mixture of zinc sulfate solution and dilute sulfuric acid. Neutral zinc sulfate solution is fed into the system, and sulfuric acid is regenerated during the plating process. Although commonly called zinc *refining*, this method of recovering zinc from its ores should properly be called *electrowinning* to distinguish it from other methods.

The mixture of depleted zinc sulfate solution and regenerated sulfuric acid formed in the electrolyzing step is returned to the leaching step. The operation, being cyclic in nature, is highly susceptible to the build-up of impurities.

Over-voltage in zinc electrolysis

Electrolysis of zinc sulfate solution results in oxygen being discharged on the anode and hydrogen on the cathode. The presence of these gases brings into play a factor, or factors, known as over-voltage or polarization. There are several theories and much confusion concerning them, but the heart of the problem is the difference between the theoretical voltage necessary and the actual voltage required to cause the reaction to take place in the cell.

Theoretically it should be impossible to deposit zinc from an electrolyte of zinc sulfate and sulfuric acid, since hydrogen should be deposited as easily as zinc. Successful deposition takes place due only to a very narrow margin of hydrogen over-voltage;

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this has been calculated to be on the order of 0.05 v, and anything causing even a slight lowering of it causes detrimental effects.

Impurities present in electrolyte

The ideal electrolyte would be an acid zinc sulfate solution containing no other elements, but this is impossible to attain. A *commercially* pure zinc electrolyte is simply a solution which, when used as an electrolyte, will give a good deposit of zinc at a high ampere efficiency; all commercial electrolytes are only relatively pure.

Elements that may be detrimental to the operation of a zinc cell and are likely to be present in significant amounts are iron, cobalt, nickel, copper, arsenic, antimony, germanium, tin, selenium, tellurium, cadmium, lead, chlorine, fluorine, and manganese.

Single impurity elements affecting the deposition of zinc can often be recognized by their effect on the deposit or their action in the cell. The effect of two or more impurities in combination is a tougher problem, because of the enormous number of combinations possible, both in respect to the elements present and their amounts. Usually a combination of detrimental elements is much more harmful than the same elements singly.

Iron: This element may be present in considerable amounts before becoming seriously detrimental. Ferrous iron is oxidized at the anode to ferric iron, which is in turn reduced to ferrous iron at the cathode, consuming power and affecting ampere efficiency. The presence of iron indicates that certain purification steps have been improperly taken, warning that other, more injurious elements may also be present. Iron may act as a weak depolarizer, decreasing formation of soluble lead compounds, and a small amount in the electrolyte might inhibit deposition of lead with cathode zinc.

Cobalt: The effect of cobalt can be seen by an inspection of deposited zinc, since it causes the formation of more or less round holes. These appear first on the back, or aluminum, side of the deposit. They may extend through the deposit, but they are usually much larger on the back than on the front. Cobalt can be tolerated in amounts of 0.010 gpl or even more, in the absence of other impurities. Detrimental effects are increased by elements such as germanium, and to a lesser degree, by higher acid concentrations. A controlled amount is sometimes used as an inhibiting agent, since it tends to reduce the amount of lead in the zinc deposit.

Nickel: Presence of this metal, in amounts above 0.0001 gpl, and in combination with cobalt or like elements, can be quite detrimental. It causes large holes to form in the deposit by resolution of zinc. However, nickel is usually removed in purification and does not cause trouble unless allowed to build up in the system.

Copper: This element is quite easily removed by ordinary purification methods, but it may be introduced by corrosion of copper bus bars or copper header bars. Its presence in the electrolyte causes severe resolution of the zinc deposit, and it deposits with zinc. It also corrodes the aluminum cathode sheets.

Arsenic: A cause of beads and sprouts on the zinc deposit, arsenic should be removed by proper purification. It is not so harmful as antimony or germanium, but its presence usually indicates the presence of these elements.

Antimony: This metal is very injurious in the electrolyzing cell in amounts of 0.00002 gpl or more. It is particularly toxic when other impurities are also present, causing extreme beading of the deposit and lack of metallic ring.

Germanium: Having a tendency to build up in the system, germanium may become a major problem even when introduced in amounts as low as 0.1 ppm of the electrolyte. It is especially detrimental in the presence of other impurities, such as cobalt or antimony. This metal causes a multitude of pinholes in the deposit which tend to overlap, resulting, in extreme cases, in either spongy metal or large areas burned away. In very small quantities, lowered ampere efficiency may be the only result.

Tin: Appreciable amounts of tin cause a lowering of the hydrogen over-voltage and ampere efficiency. In addition, the zinc deposit has a very shiny surface with prominent vertical ridges, and the crystalline structure is changed to some extent. Tin causes a marked increase in the amount of lead in the deposit. Fortunately it rarely appears in the electrolyte to any extent, but concentrates containing large amounts of tin are regarded with disfavor.

Selenium: The presence of selenium in amounts of 0.0001 gpl produces a zinc deposit with heavy vertical ridges. Larger amounts raise spots on the face of the cathode with corresponding depressions on the reverse side, while excessive amounts cause severe resolution of the zinc deposit. Selenium is seldom encountered in harmful amounts unless it is present in the zinc concentrate in excessive amounts.

Tellurium: This element should be removed in the normal purification, but the presence of even small amounts of tellurium results in a deposit very similar to that resulting from selenium. Tellurium is especially harmful in the presence of cobalt. It can often be detected in the manganese dioxide sludge.

Cadmium: This impurity is nearly always found in the electrolyte to some extent: 0.0005 to 0.0001 gpl are not unusual. Cadmium has little adverse effect on ampere efficiency, but it plates out with the zinc, causing an impure product. It is normally quite easy to reduce the cadmium content in the electrolyte to small amounts, but it is extremely difficult to eliminate entirely.

Lead: While rarely introduced with the electrolyte in significant amounts, lead appears in the zinc deposit if present. The normal source of lead is from corrosion of the anodes or tank linings. Impurities such as chlorine or fluorine tend to increase its corrosion rate. It can be controlled by the addition of certain inhibiting agents, a lower operating temperature, and the use of lead-alloy anodes.

Chlorine: This impurity can be present in amounts as much as 0.02 to 0.04 gpl without showing a marked effect on ampere efficiency. Chlorine is relatively harmless unless present as chloride, which is oxidized at the anode into perchloric acid. Chlorine contributes to the presence of lead in the deposit, effects the corrosion of aluminum, and in large amounts contributes toward the zinc deposit adhering tightly to the aluminum cathode.

Fluorine: This is the chief contributor to *sticking*, the name given to the zinc deposit adhering tightly to the aluminum cathode, sometimes so tightly that its removal by ordinary means becomes impossible. The chief method of combating fluorine is by conditioning the electrodes in the electrolyte for a short time before applying power. This tends to restore the protective film on the aluminum cathode.

Manganese: This metal is almost always present, but its compounds are considered harmless or even beneficial. Manganese dioxide is deposited at the anode during electrolysis, and a certain amount of the more highly oxidized compounds may also be formed. Some of the manganese dioxide adheres to the anode, and a portion falls to the bottom of the cell; a smaller portion is carried out of the cell with the depleted electrolyte. Under certain operating conditions, manganese dioxide reduces anode corrosion. A certain amount of impurities may also be removed from the electrolyte through adsorption in it.

Control of impurities by

a) Selection of ores or concentrates

Individual mines, or ores from particular localities, may contain one or more impurities in unusual amounts. These must be watched for in selecting material for treatment. The character of an ore or concentrate may also change abruptly at any time. This makes constant vigilance mandatory on the part of plant operators.

Practically any element, including zinc, can qualify as an impurity, or undesirable element, if it occurs in unusual amounts or in combination with other elements. Certain compounds of zinc certainly fall within this classification; the carbonate is a good example.

b) Roasting

Roasting can exert considerable influence on the amount of certain elements left in the roasted material. Elements normally of concern in the roasting step are iron, lead, and bismuth. Elements that may be partially eliminated or controlled during the roasting process are fluorine, chlorine, sulfur, selenium, and tellurium.

When the iron content of a concentrate is unusually high, zinc and iron will combine at elevated temperatures to form insoluble zinc ferrites. Thus, initial roasting temperatures must be controlled to minimize the amount of ferrites formed. A concentrate with a high lead content requires extra precautions in roasting to avoid the loss of lead through volatilization. Unless prevented, lead loss can have a considerable influence on the economics of the operation. Excessive amounts of bismuth are rarely encountered, but bismuth may be reduced to the metallic form within the furnace to the extent that roasting is prevented. Particles of zinc oxide may also become coated with metallic bismuth, which will seriously affect the solubility of the product.

Some elements are removed to a considerable degree during roasting. If these elements can be controlled at this point, a great deal of trouble can be avoided in the balance of the process. Fluorine is largely eliminated during roasting by being volatilized, which is the only adequate method of control. As a general rule, elimination of fluorine is improved by an increase in roasting time, an increase in temperature, and adequate exposure of the material to the roasting atmosphere. Chlorine is eliminated under the same conditions. Selenium and tellurium may be volatilized to a considerable extent, but they may reappear in the flue dusts. Sulfur is removed by conversion of the sulfides to oxides. A certain amount of sulfur can be combined with zinc as zinc sulfate. The roasting step is often controlled to produce as much zinc sulfate as needed to offset the loss of sulfate-ion in the residues and to keep the system in balance as to sulfuric acid.

c) Leaching and purification

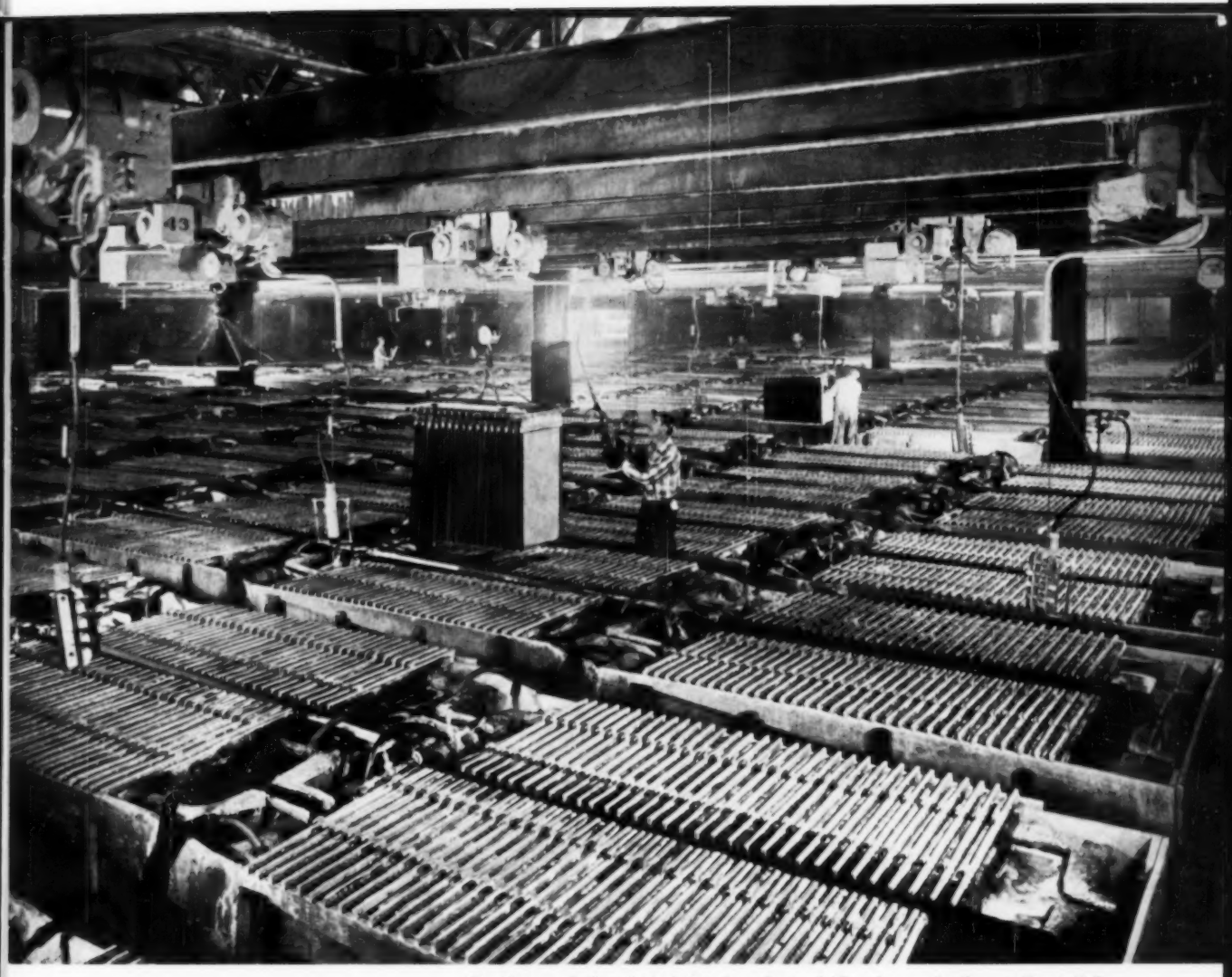
This is actually the most intricate and involved part of the whole process. It is also the most important, since it is this step that determines whether the electrolyzing step can be carried out successfully.

Leaching of the zinc oxide may be carried out in one or more stages. In any case, leaching results in a point of separation between the soluble and insoluble elements present. Barium, silver, gold, lead, and bismuth are normally insoluble in dilute sulfuric acid and will not be considered further.

One of the most important methods of purifying the zinc sulfate solution is by iron purification, which all plants utilize at some point. This is carried out by oxidizing any ferrous iron present to the ferric state and then adding a neutralizing agent to precipitate iron as ferric hydroxide. Additional iron can be added as a solution of ferric sulfate if desired. The neutralizing agent can be limerock or an excess of the zinc oxide in roasted concentrates. Precipitation of ferric hydroxide assists in the removal of other impurities, such as arsenic, antimony, germanium, etc., that are much more difficult to remove. The part played by the iron has long been a subject of debate, but is generally considered to be due either to the formation of basic salts with other elements or to an adsorption process, and may be a combination of both. Formation of ferric hydroxide and precipitation of associated elements are closely coupled with pH of the solution, which must be 5.7 to 6.0. The reaction must be given time to take place, and increased temperatures usually improve the elimination of impurities.

Manganese, cobalt, nickel, fluorine, and chlorine are rarely precipitated to any extent by an iron purification. Manganese seldom causes trouble even if present in rather large amounts. Cobalt and nickel are usually present in very small, but important, amounts. The removal of these elements in an iron purification is too small to have any bearing on their control. Copper is partially precipitated, but the amount remaining is enough that an additional step is necessary for its control. Fluorine is practically untouched in an iron purification, but chlorine may be removed as silver chloride if sufficient silver is present.

Arsenic, antimony, and germanium are precipitated in an iron purification, but they are increasingly difficult to remove in the order given. Arsenic is usually almost completely precipitated, although the trivalent state is more difficult to control than the quinquevalent. Antimony is fairly easy to remove when in the trivalent state, but pentavalent antimony is rarely removed to any extent. Precipitation of germanium is slow and



Tankhouse of the electrolytic zinc plant of The Anaconda Co. at Great Falls, Mont. This building houses 1278 lead-lined cells.

almost entirely dependent upon the co-precipitation with iron. Additional purification steps are necessary if any appreciable amount of germanium is present.

Tellurium can usually be precipitated here, especially if it is present in the quadrivalent state. Selenium is not completely precipitated and may cause trouble in electrolysis if present at this point. Silicon is usually brought under control by removal along with the ferric hydroxide, but large amounts require special treatment. Iron is seldom removed completely, but the amount remaining is small enough that it can be considered under control.

Elements such as tin, gallium, indium, thallium, and mercury are usually present in extremely small amounts. They are reduced in amount to the point where they seldom have any bearing on further steps in the process.

d) Zinc dust purification

Removal of impurities by precipitation with zinc dust, or blue powder, in a neutral solution depends upon the reduction of the metals below zinc in the electromotive series to the metallic form. Copper, cadmium, germanium, arsenic, and antimony are normally controlled in the zinc dust purification.

The activity of metallic zinc can be increased by the presence of those same metals that have an injurious effect on electrolysis. The action is the same in both cases, lowering of the hydrogen overvoltage on zinc. In order to take advantage of this increased activity, easily removed elements, such as copper or arsenic, are often added. The presence of such impurities will aid in the removal of other elements, such as antimony and germanium, more difficult to control. Cadmium is quite easy to remove, but it has a tendency to redissolve, especially if the solution is aerated during purification and filtration. Several methods are used to avoid the resolution of cadmium, such as the addition of an excess of zinc dust just prior to filtration, or by making the purification in two or more stages. Copper is removed immediately upon contact with zinc dust and seldom presents a problem in its control.

e) Special purification methods

Control of cobalt in the system is very important, especially if germanium is also present. In theory, cobalt should be removed readily with zinc dust. In practice, the removal is difficult, as zinc sulfate appears to suppress completely the ionization of cobalt sulfate. Several methods have been de-

veloped to control the amount of cobalt reaching the cells.

The addition of potassium antimony tartrate or antimony trioxide as a dry solid to the zinc dust purification will remove as much as 0.002 gpl Co from the solution. The addition of more of the antimony compound will not increase the amount of cobalt removed, and it is extremely difficult to go below 0.0005 gpl Co by this method. An excess of the antimony compound may carry over into the electrolyzing cells with a detrimental effect. Arsenic compounds react in the same manner, and the possibility of forming poisonous arsine or stibine should be considered when using either of these compounds.

Nitroso-Beta-Naphthol, in a separate purification, will remove cobalt from solution in quite large amounts. To be completely effective, iron and copper must be removed ahead of this step, as the reagent will remove these elements preferentially to cobalt. Cobalt removal is due to formation of cobalti-nitroso-beta-naphthol. Cobalt can be recovered from the precipitate as a byproduct.

A hot, copper-arsenic-zinc dust purification is effective in removing cobalt, nickel, antimony, and germanium. This purification is usually made on a clarified solution and utilizes copper sulfate solution or metallic copper, arsenic trioxide dissolved in a caustic solution, and metallic zinc dust. Adequate ventilation is necessary. Use of 2.5 gpl Cu, 0.2 gpl As, and 2.5 gpl Zn dust will reduce cobalt from 0.05 to 0.001 gpl or less, and nickel from 0.01 gpl to trace amounts. Antimony and germanium are quite effectively controlled by this purification. This is also the only purification method that can be used to control fairly large amounts of nickel economically.

Cobalt can also be removed from solution by the addition of an aqueous solution of sodium ethyl xanthate to a well-oxidized solution. Potassium permanganate or copper sulfate can be used for this purpose. Copper takes part in the reaction and should be present. Efficiency of the purification is improved if cadmium is first reduced to small amounts.

Extra iron purifications are often used to reduce the amount of antimony and germanium in solutions that are relatively free of cobalt and nickel.

Chlorine can be removed by a special purification in which an acidified solution is treated with silver sulfate. The precipitated silver chloride is treated with sulfuric acid and zinc dust to recover the silver. There are no good methods to control fluorine once it is in solution.

Silicon is usually quite well controlled during the neutralization step through precipitation with an excess of the neutralizing agent. The presence of soluble silica in the system will improve the removal of other impurities, but beneficial results are obtained only if the coagulation and precipitation of silica are also carefully controlled. The presence of unprecipitated silica in the system will result in poor settlement and difficult filtration.

Elements such as sodium, potassium, calcium, and magnesium may be present in fairly large amounts without detrimental effects. Calcium may become a nuisance through precipitation of gypsum in pipelines and other equipment, but is limited in its solubility. Magnesium can build up to the point where it interferes with the solubility of zinc. A special purification step, consisting of an acid leach on the unroasted concentrates, is an effective method of controlling magnesium.

Normal amounts of selenium and tellurium are usually under good control, but excessive amounts of either should be avoided by selection of the concentrates, where possible. If a large amount of tellurium enters the system, it will appear in the manganese dioxide sludge formed in the electrolyzing cells. Discarding this sludge is about the only way to remove tellurium.

Barium rarely causes trouble as it is normally quite insoluble in dilute sulfuric acid, but any soluble barium will tend to accumulate in the system. Barium chloride will cause difficulties in settlement of solids and in filtration of residues.

Manganese dioxide is an efficient oxidizing agent, and it is quite commonly used. The manganese content of the solution may be as high as 10 to 20 gpl without detriment, except possibly to the solubility of zinc. Manganese is precipitated at the anode as manganese dioxide. The amount removed is dependent more on other conditions existing in the electrolyzing step than on the manganese content of the solution. Manganese content can be controlled by discarding the manganese dioxide removed from the cells.

Control of impurities during electrolysis

Addition agents, such as glue, goulac, and metal salts, are often added to improve ampere efficiency and to improve the physical character of the deposit. One theory on the use of addition agents is that certain substances added to the electrolyte will combine with the impurities present and cause them either to precipitate or to become inactive.

A colloidal solution or suspensoid such as glue is formed of neutral substances, but the particles migrate under the influence of an applied electromotive force. The particles will deposit in clusters on points of high current density and reduce the amount of current at these points. This tends to smooth out the deposit. Beta-Naphthol has been used alone or in conjunction with glue as an addition agent. Hydrogen over-voltage tends to be increased in the presence of colloids.

Other factors that will decrease the hydrogen over-voltage and ampere efficiency are high current density, impurities in the electrode metal, presence of organic compounds, a long deposition time, and elevated temperatures. An improvement of any of these factors will tend to increase the efficiency of electrolysis.

Addition of either strontium carbonate or barium carbonate to a zinc electrolyzing cell will materially reduce the amount of lead deposited with the cathode zinc. Both methods are patented.

Conclusion

The operating conditions within individual plants vary from day to day and from month to month. The many factors involved, some of which may be unknown, result in the impossibility of making positive statements about the effect of impurities under all conditions. However, this brief coverage of a large subject is hoped to be the start toward more information being made available about the action of impurities in the zinc electrolyzing process.

FLUIDIZED BEDS FOR METAL PRODUCTION

Metal production by vapor deposition in a fluidized bed has been the result of applying the chemistry of vapor plating to the engineering involved in handling fluidized solids. Commercial possibilities depend on availability of low-cost feeds.

by J. H. Oxley and I. E. Campbell

Numerous industrial processes take advantage of the fact that solids suspended in turbulent gas streams exhibit many properties of fluids and constitute an excellent medium for physical and chemical reactions.

The first successful large-scale application involving the use of these fluidized solids was the catalytic cracking process, which employs powdered catalysts in the conversion of crude petroleum into gasoline.[1]

Other applications of the fluidized-solids technique followed rapidly after the success of the fluidized petroleum cracking process in 1942. Most of the major chemical and petroleum companies are now using or developing fluidized processes. Applications either in the commercial or development stage include oxidation, hydrogenation, halogenation, and carbonization of hydrocarbons;[2-5] hydrogenation, gasification, sulfation, and carbonization of coal or coke;[6-10] retorting of oil shale;[11, 12] halogenation, roasting, and reduction of ores and inorganic intermediates;[13-20] calcination of limestone and cement;[21, 22] drying of solids;[23] adsorption of gases;[24, 25] condensation of sublimable solids;[26] mist removal;[27] and cooling of nuclear reactors.[28]

In the continuing search for improved methods of producing metals, a number of research investigations are now being directed toward the development of fluidized-bed reduction processes because these processes can in most cases be operated continuously. Many variations of the fluidized-bed process can be considered of potential commercial interest for the production of metals, but perhaps the most interesting variation involves the deposition of metal on fluidized seed crystals of the same metal.

If compounds capable of being reduced to the metal are introduced into a fluidized bed of metal powder, either as suspended solids, or liquids, or as vapor feed, the metal formed by the reduction process can be deposited on the seed crystals and, as the crystals grow in size, they may be withdrawn periodically without interrupting the reduction process. By proper control of the fluidizing gas, the powder can be routed through the system so as to permit the regeneration or addition of seed metal, thus making possible uninterrupted operations.

The potential advantages of a fluidized-bed reduction process are substantial. In addition to the possibility of continuous operation, the process has high capacity-per-unit-volume and, in many cases, is suitable for the production of metal of very high purity. The limitations of the process, as applied to the production of high-purity metal, lie primarily in the problems associated with the handling of large volumes of high-purity gases at high temperature, and in the difficulty of maintaining fluidization at elevated temperatures, where some metals have a strong tendency to sinter.[29] If this sintering process cannot be controlled, then the reactor becomes choked and discharge of the product is impossible. If the byproduct of the reduction reaction is a liquid or solid with a relatively low vapor pressure, then bogging or defluidization of the bed may occur at intermediate temperature levels.

It would appear, however, that the potential advantages of fluidized-bed reduction processes are such that they are of commercial interest, particularly for the production of the more refractory metals with which the sintering problem is minimized.

Process entirely automatic

Ultimately, the ideal fluidized-bed process should permit uninterrupted production of the metal with automatic addition of feed materials and withdrawal of high-quality product at will. A preferred mode of operation is outlined in Fig. 1. The crude metal chloride feed can be obtained by selective chlorination of an appropriate ore, carbide, or ferroalloy of the desired metal. This crude chloride is purified preferably by distillation, and then pumped directly into a bed of metal granules suspended at elevated temperatures by a fluidizing stream of hydrogen gas. Chloride vaporizes in the bed where subsequently it is reduced to metal, which deposits on the extended surface provided by the metal granules in the fluidized bed. Excess hydrogen from the reactor, containing byproduct hydrogen chloride gas, is then cooled and washed with water or alkaline solution to remove the hydrogen chloride. This scrubbed hydrogen is then dried and recycled through a heat exchanger back

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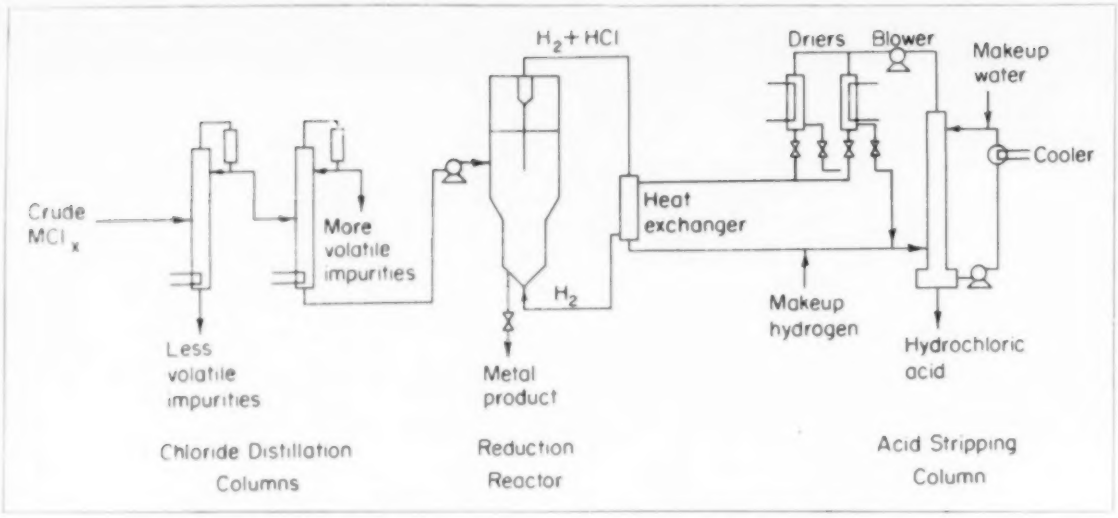

Fig. 1—Schematic flow diagram for hydrogen reduction of a metal chloride in a fluidized bed.

into the reactor. Makeup reductant hydrogen is added periodically to maintain a balance of pressure, and makeup water is introduced in proportion to the rate of removal of hydrochloric acid.

Continuous operation of such a metal-production process could be achieved by withdrawing the product from the reduction reactor by means of conventional equipment. Part of this withdrawal product then could be comminuted and returned to the reactor to provide seed material for further metal deposition. This grinding scheme is particularly attractive for a hydrogen reduction process in which the product metal forms a salt-like hydride, as those hydrides are quite brittle and are readily comminuted even within the reactor itself. The hydride formation is generally reversible, and metal low in hydrogen can be obtained by fluidizing the hydride with an inert gas at elevated temperatures.

Metals which might be prepared by chemical reduction, thermal pyrolysis, or disproportionation of their halides in fluidized-bed process include Al, Be, B, Cr, Co, Cb, Cu, Ge, Hf, Fe, Mn, Mo, Ni, Si, Ta, Sn, Ti, W, U, V, and Zr. It is obvious that the process is not restricted to halide feeds and that if oxides, sulfides, or other compounds can be produced with a satisfactory degree of purity at a lower cost, they may be substituted to advantage in some cases. Examples of metals whose oxides can be purified at reasonable temperature levels on the basis of selective volatilization are germanium and molybdenum. Other compounds that could be considered as feeds for a fluidized-bed process in special cases are carbonyls, carbonyl halides, nitrosylcarbonyls, and alkyls.

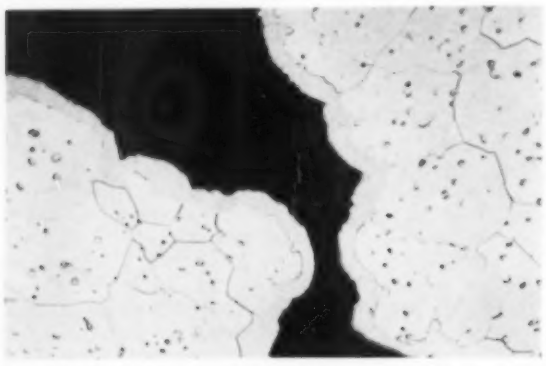

Fig. 2—Metallic film deposited by reduction of a volatile metal chloride in a fluidized bed.

Applications to iron ore

Because of the advantages of the fluidized-bed technique in relatively large scale operations, it is not surprising that a number of companies are piloting fluidized-bed processes for the direct reduction of iron ore.[16] These fluidized-bed reduction processes, based on nonvolatile oxide feeds, are feasible because of the availability of high-grade iron ores. It is interesting to note that one of the earliest patents covering a fluidized-bed process was awarded in 1879 and covered the reduction of powdered iron ore.[17] This application was largely neglected until after World War II. However, there are at least three different fluidized-bed iron ore reduction processes now being piloted in the US.

These processes generally involve a fluidizing stream of gas containing appreciable amounts of hydrogen or carbon monoxide for reduction of the ore to iron. Operating temperatures vary from 900° to 1600°F and pressures up to 20 atm. The major difference between these iron ore reduction processes and the deposition processes described in this paper is that the relatively coarse ore particles are usually individually reduced to discrete iron particles. In the fluidized-bed deposition process employing volatile feeds, the volatile metal compound is reduced and deposited on the metal particles already present in the reactor.

A slight modification of the deposition technique to prepare molybdenum and nickel films or ceramic powders in a fluidized bed was reported several years ago. Hydrogen reduction of both metal chlorides and carbonyl was studied with the purpose of obtaining improved materials for the manufacture of cermets. However, difficulty evidently was encountered in trying to maintain fluidization during deposition.[18]

The only nonferrous metallurgical fluidized-bed process for metal production which has been described in the literature involves the sodium reduction of titanium tetrachloride to produce granular titanium. This process originally was patented in the UK but now also is covered by a US patent.[21] A mixture of argon and titanium tetrachloride vapor is used to fluidize a bed of metallic titanium and sodium chloride particles at a temperature somewhat below the melting point of the salt. The use of a mixing impeller immersed in the powder bed to prevent agglomeration of the mixed solids also has been patented.

Liquid sodium is added continuously at the top of the fluidized bed, and the solid titanium and salt products are withdrawn continuously in proportion to the feed rate of the reactants. These product solids then are reheated in a separate vessel to a temperature somewhat above the melting point of sodium chloride so as to render the titanium less reactive to the water used in a subsequent washing step.

Hydrogen, sodium, and zinc as reducers

Although sodium is one of the strongest of the various possible reducing agents, it is not always the best. Hydrogen is quite satisfactory thermodynamically for many metal halides and oxides, and hydrogen is generally easier to purify and handle than sodium. In addition, both the hydrogen feed and the byproduct hydrogen halide from a halide-reduction process would be gaseous within the practical range of operating temperatures and pressures and, therefore, fluidization of the granular metal product would be considerably simplified.

Although zinc is a less powerful reducing agent than sodium, it is particularly attractive as a reducing agent in the fluidized bed reduction of chlorides whenever thermodynamic considerations are favorable. Because zinc chloride is more volatile than zinc metal, the byproduct zinc chloride is vaporized out of the reactor as soon as it is formed. The same is true of magnesium iodide in a process based on the reduction of an appropriate iodide.

A volatile feed material for fluidized-bed reduction not only permits a preliminary distillation purification to be carried out, but also permits maximum reduction efficiency in the production reactor itself. The problems of rapidly heating solid feeds to a suitable reaction temperature and minimizing concentration gradients of the reductant as a result of finite diffusion rates into and out of solid particles are obviated by the use of a volatile feed. If a volatile compound of the metal cannot be produced cheaply, then grinding of the relatively nonvolatile material to provide a fine powder feed would normally appear to be desirable.

With volatile feeds, the reduction apparently takes place at the surface of the metal already present as discrete granules in the fluidized bed. It has been found at Battelle that the metal is deposited preferentially on the extended surface provided by the fluidized bed, and that the undesirable consequence of gas phase nucleation, such as elutriation of the reduced metal from the reactor, is a relatively rare phenomenon.

The type of metal deposit that is obtained with volatile feeds is shown in Fig. 2. These deposits were obtained by reducing a volatile metal chloride with an excess of hydrogen in a fluidized bed of another metal. Metallographic examination of these coated particles shows that the metal plated out on the surface of the particles in the fluidized bed has a film of relatively uniform thickness. Hence, in the case of a distribution of metal particle sizes in the fluidized bed, the particles generally will grow in proportion to their surface area. However, for particles with a diameter of a few microns, sintering and other surface effects frequently lead to a more complex growth relationship. The product obtained by the use of finely ground solid feeds usually is more irregular than the deposits shown in Fig. 2, but otherwise is similar. These irregular deposits evidently occur by sintering finely divided feed or reduced metal crystallites to the larger metal particles already present in the reduction zone.

Evaluation

The technical feasibility of these fluidized-bed reduction processes has been verified for a variety of metals in both laboratory and bench-scale reactors. Metal production rates are substantially higher than those of current commercial processes for the production of refractory metals. Because the capital investment is low, and since these processes can be operated on a continuous basis with a resultant saving in labor, these fluidized bed reduction processes appear to offer substantial cost savings in many cases. A fluid-bed process has the further advantage of being able to produce a premium quality product.

Application of this processing technique for the production of metals should be commercially exploited soon in a number of different fields. These fields include the production of refractory metals, both as pure metals and as alloyed powders, the coating of ceramic powders particularly for utilization in nuclear fuel systems, and the production of catalysts by deposition of catalytically active metals on inert support powders.

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John Chipman, 1959 President, Metallurgical Society of AIME

John Chipman, third President of The Metallurgical Society of AIME, is head of the Dept. of Metallurgy at Massachusetts Institute of Technology. Dr. Chipman has contributed extensively to the field of metallurgy, and many of his papers have appeared in AIME publications. He was Chairman of the Iron and Steel Div., AIME, in 1957, and president of the American Society of Metals in 1952. For many years he has served as a member of the AIME Physical Chemistry of Steelmaking committee and the Publications committee. Dr. Chipman, who enjoys listening to the Boston Symphony during his few leisure moments, graduated from the University of the South and received his Ph.D. in physical chemistry from the University of California at Berkeley in 1926. During World War II he was chief of the Metallurgy Section, Metallurgical Laboratory, of the Manhatten Project. He has worked with a number of Government scientific and technical committees since the War. Particularly well known for his research concerning the role of oxygen in iron and steelmaking, Dr. Chipman joined the faculty at MIT in 1937, assuming his present position in 1946. He is a recipient of the Robt. W. Hunt Medal (AIME), the Henry M. Howe Medal (ASM), the Henry Bessemer Medal (UK), the Losana Gold Medal (Italy), the John A. Brinell Medal (Sweden), and has been selected to deliver The Howe Memorial Lecture (AIME). He is a member of Sigma Xi, Phi Lambda Upsilon, Phi Beta Kappa, and Alpha Chi Sigma.

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AIME

METALLURGICAL SOCIETY OF AIME

NEWS

METALLURGICAL SOCIETY 1959 AWARD WINNERS

The following honors will be conferred at the AIME Annual Meeting in San Francisco, February 15th to 19th:

The James Douglas Gold Medal, for recognition of distinguished achievement in nonferrous metallurgy: to Clyde Williams, Clyde Williams & Co. Dr. Williams gained his first professional experience in mining and smelting plants. He holds the Medal of Merit and a Presidential Citation as a result of his work on civilian committees advising the War Production Board and other Government agencies immediately prior to, and during World War II. He joined the staff of Battelle Memorial Institute in 1929 as assistant director, and resigned from the presidency in 1957 to head his research and management advisory firm.

Extractive Metallurgy Division Award, for the best paper in the field of extractive metallurgy: jointly to William A. Krivsky, Union Carbide Metals Co., and Reinhardt Schuhmann, Jr., Purdue University. Dr. Krivsky received his Sc. D. from Massachusetts Institute of Technology in 1954. He is responsible for initiating and co-ordinating research relating to the technology of ferro-alloys, titanium, columbium, tantalum, vanadium, and ceramic materials. He is also credited with several publications and patents concerning extractive metallurgy.

Dr. Schuhmann received his Sc. D. from MIT following graduate study in mineral dressing. As an instructor, assistant professor, and associate professor at MIT, he taught mineral dressing and pursued fundamental research on flotation and comminution. During the war, in collaboration with A. Gaudin, he developed processes for the beneficiation of Bolivian tin ores. Dr. Schuhmann joined Purdue in 1954.

The Benjamin F. Fairless Award, for recognition of distinguished achievement in iron and steel production and ferrous metallurgy: to James L. Mauthe, Youngstown Sheet and Tube Co. Mr. Mauthe began his career while attending Pennsylvania State University, by working in the blast furnace department of Carnegie Steel at Duquesne. After graduating in 1913, he returned as a blast furnace laborer, working his way through a succession of positions and companies arriving at the presidency of YS&T Co. in 1950. In 1956 he was elected chairman of the board.

Robert W. Hunt Medal (silver), for the best original paper on iron and steel contributed to the Institute: to T. W. Crosta.

Daniel C. Jackling Award and Lecture, for significant contributions to technical progress in the fields of mining, geology, or geophysics: to Ralph S. Archibald, North Range Mining Co. Mr. Archibald holds an E.M. degree from Lehigh University. He has been in the field of geology since 1907, founding his own organization in 1933. His association with various companies has carried him throughout North and South America. At the time of his retirement in 1954, he was consulting geologist for Inland Steel Co; Mr. Archibald retains his position as chairman of the board at North Range Mining Co.

J. E. Johnson, Jr. Award, for exceptional ability in research, invention, or contributions to the technical literature of those branches of the technology of the iron and steel industry related to metallurgy of pig iron: to Clarence T. Marshall, Pittsburgh Coke & Chemical Co. Mr. Marshall was recently a member of a technical delegation named by the US Dept. of State to study the coke, iron, and steel industry in Poland. He has made substantial contributions to merchant blast furnace practice, ferromanganese production, and stream and air pollution abatement. He represents the fourth generation of his family to serve in the merchant pig iron and ferromanganese industry.

Anthony F. Lucas Gold Medal, for distinguished achievement in improving the technique and practice of finding and producing petroleum: to John T. Hayward.

A native of England, Mr. Hayward came to the US in 1927 as chief engineer of the Phoenix Oil & Transport Co. As a result of his visit, he became a citizen in 1931 and joined the staff of Barnsdall Oil Co. During World War II, he worked with the Navy Dept. as chief scientist at the underwater warfare test station in Solomons, Md. In 1947, drawing upon his training as a marine engineer, he designed a self-contained mobile platform, the first submersible drilling barge. Mr. Hayward is now semi-retired.

(Continued on page 140)

Technical Translations Listing Available

The US Dept. of Commerce has started publication of a semi-monthly periodical designed to serve as a central source of information in the US on Soviet and other technical translations available to science and industry.

The periodical, *Technical Translations*, incorporates the Special Libraries Association's *Translations Monthly*. Information includes lists and abstracts of translated material available from US Government sources, SLA, co-operating foreign governments, educational institutions, and private sources.

Subscriptions cost $12 per year (slightly higher in foreign countries); single copies are $0.60. Address requests to *Office of Technical Services, US Dept. of Commerce, Washington 25, D.C.*

AROUND THE SECTIONS

• **Mexico section:** Speaker at the December meeting was Luis de la Peña, technical director of Recursos no Renovables. His subject was *Rusumen de las actividades del Consejo.* The meeting was conducted by vice president S. F. Treviño.

• **Mohawk-Hudson section:** Professor Bruce Chalmers, Harvard University, spoke on *Structure of Large-Angle Grain Boundaries* at the December meeting. MIT's John Chipman discussed *The System CaO-Al_2O_3-SiO_2 Properties of Liquid Solutions* at the January session.

• **Reno subsection:** The US Bureau of Mines in Reno acted as host at a luncheon-meeting on December 12th. A complete tour of the facilities of the US Bureau of Mines laboratories and building followed talks by D. J. Bauer *(Development of Equipment and a Process for Producing Pure Cerium Metal)* and Edward Morrice *(Electrowinning of Cerium).* Both speakers are metallurgists with the USBM.

• **North Pacific section:** New officers of the Section, as announced by D. L. Anderson, secretary-treasurer, are: chairman, Ralph A. Watson; vice chairman, Merrill C. Teats; secretary-treasurer, Donald L. Anderson; correspondence secretary, Marshall T. Huntting.

• **St. Louis section:** Lute J. Parkinson, Colorado School of Mines, recounted his experiences while completing exploration surveys for diamonds in Africa, at the December meeting. A number of slides showed the primitive exploration and mining methods used in that location. Philip N. Powers, Inter-Nuclear Co., addressed the group at the Hotel York in St. Louis on January 9th. His talk concerned the installation of atomic power plants throughout the world.

• **Southern California section:** Scheduled for the first morning session of Metals Branch, 11th Western Metal Congress, March 16th to 20th, is the subject *Recent Advances in the Physics of Metals.* Other topics under discussion will be: *Metallurgy of Thermo-Electric Materials, Materials for Extremely High Temperatures,* and *Radiation Effects in Materials.* Los Angeles' Ambassador Hotel will be the host.

Annual Lecturers Selected for 1959 AIME Convention

Clarence E. Sims and Frederick Seitz have been selected as the 1959 Howe Memorial Lecturer and the 1959 IMD Lecturer, respectively. They will speak at the Annual Meeting of AIME in San Francisco. Dr. Sims will discuss *The Nonmetallic Constituents of Steel;* the subject of Dr. Seitz' lecture is *The Effects of Irradiation Upon Metals.*

Dr. Sims has been associated with Battelle Memorial Institute since 1936. A graduate of the University of Illinois, he is the author or co-author of about 80 technical publications, most of them in the field of ferrous metallurgy. Previous awards include the Robert W. Hunt Medal, the John A. Penton Gold Medal, and the Sauveur Achievement Award.

Dr. Seitz is the head of the Dept. of Physics at the University of Illinois. He has been associated with the University of Rochester, the University of Pennsylvania, General Electric Co., and Carnegie Institute of Technology. From 1946 to 1947 he was the director of the training program in atomic energy at Oak Ridge. He has published more than 130 papers.

(For information about the Daniel C. Jackling Lecture, see the Society award winners.)

Nuclear Congress to be Held in April

Metallurgy and Materials, Fuel Technology, Isotope Application, Waste Disposal, and Heat Transfer, are among the discussions scheduled for April 5th to 10th at the Public Auditorium in Cleveland during the 1959 Nuclear Congress.

Features of the 40-session meeting will be a trade show (the Atomfair), talks devoted to problems of industrial management in the nuclear field, and papers dealing with advances in reactor technology, the use of radioactive materials, and laboratory problems in radioactive materials.

More than 30 engineering, scientific, and management groups are sponsoring the Congress, whose theme is *For Mankind's Progress.* Co-ordinating agency is the Engineers Joint Council.

For additional information or early registration, contact *Fred Howell, Engineers Joint Council, 29 W. 39th St., N. Y. 18, N. Y.*

A summary of the program will appear next month.

Award Winners

(Continued from page 139)

Mathewson Gold Medal for the paper or series of papers representing the most notable contribution to metallurgical science: to John J. Gilman, General Electric Co.

Dr. Gilman holds a doctorate degree from Columbia University. While at Columbia, he was a research metallurgist at Crucible Steel Co., where he worked on the sigma phase in stainless steel and on tool steels. At the General Electric research laboratory in Schenectady, he has worked in the field of plasticity and fracture of crystals and its interpretation in terms of dislocations. In 1958 he was chairman of the Physics and Chemistry of Metals committee, IMD.

Mineral Industry Education Award, for distinguished contributions to the advancement of mineral industry education: to Allison Butts. Professor Butts was a member of the Lehigh University faculty from 1916 until 1956, when he became Professor Emeritus of Metallurgy. He has been associated with the National Defense Research Committee, the American Silver Producers' Research Project, and UNESCO. In the latter position, he organized research in the Institute of Materials and Processing at the Technical University of Istanbul.

Robert Peele Memori l Award, to encourage young men in creative work in mining, geology, and geophysics, and to recognize significant achievement in authorship in these fields: to Frank R. Jones, National Lead Co. Mr. Jones is a graduate of the University of British Columbia. He has worked chiefly in British Columbia.

Rossiter W. Raymond Memorial Award, for the best paper published by a member of the Institute under 33 years of age—based primarily on proficiency of organization of the material and the literary style: to John J. Gilman (see Mathewson Award).

The William Lawrence Saunders Gold Medal, for distinguished

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Books

(Continued from page 99)

Lehrbuch des Walzwerksbaus, by A. I. Zelikow, *VEB Verlag Technik,* Berlin, Germany, 538 pp., 36DM, 1957—This volume, a German translation from the Russian, gives a comprehensive treatise on rolling mill construction. It also deals with the subject roll stands and roll trains, and the forces involved.

Electric Furnace Conference Meets in Detroit

Vacuum processes, sponge iron, ferro-alloys, and calcium carbide featured

Chairman A. C. Ogan addresses Conference members at the Fellowship Dinner. Below, AIME Secretary Ernest Kirkendall, left, accepts a special certificate from V. E. Zang, executive committee chairman, recognizing his services to the Electric Furnace Committee from 1946 to 1954.

The Sixteenth Electric Furnace Conference, held in Detroit at the Statler Hotel, December 3rd to 5th, featured papers on production in electric furnaces of ferro-alloys, calcium carbide, and other products. This was the first conference not devoted exclusively to use of the electric arc furnace for steel.

The opening technical session began with an historical paper on the electric furnace ferro-alloys industry in the US, presented by J. H. Brennan, Electro Metallurgical Co., and coauthored by A. G. Dunn and C. M. Cosman, Vanadium Corp. of America.

On Friday, December 5th, such subjects as the history of calcium carbide manufacture, the tapping and casting of calcium carbide, and electrode holders were covered in *Special Arc Group* technical sessions.

Two subjects of topical interest —direct reduction of iron ore, and vacuum techniques for obtaining high-quality steels—dominated the technical program. A paper on *Direct Reduction of Iron Ores* was presented by Marvin J. Udy of Strategic-Udy Processes Inc. The M. W. Kellogg Company sponsored the presentation of a motion picture showing the operation of a special process at Hojalata y Lamina, in Monterrey, Mexico, that produces 200 tpd of sponge iron. (JOURNAL OF METALS, no. 12, 1958, pp. 806 to 807).

In connection with obtaining high-quality steel, papers were presented on vacuum stream degassing, ladle degassing, and a review of the technical conference on *Quality Requirements of Super-Duty Steels*, Pittsburgh, May 5 to 6, 1958. The technical session covering this material was organized by the Physical Chemistry of Steelmaking Committee of the Iron and Steel Div.

The annual Fellowship Dinner held in the Grand Ballroom of the Statler Hotel on December 4th, featured a talk on commercial aspects of stainless steels in our economy by M. K. Schnurr, president of the Stainless and Strip div., Jones & Laughlin Steel Corp. in Detroit. Mr. Schnurr expressed the opinion that two new developments influencing the future of stainless steel are vacuum melting techniques and the supply of iron independent of the blast furnace.

The greatest future for the electric furnace is dependent upon the substitution of another raw material source other than scrap. Because chromium and nickel are the principal special raw materials, the problem of an assured continued supply is also of great importance. Mr. Schnurr advised that the stainless steel market has experienced sustained growth in spite of high selling prices. Approximately 60 pct of stainless steel goes to the basic engineering market where other materials cannot do the job; the balance is used for non-engineering purposes. The future is bright: research is meeting the technical advances, and market development seems assured in such growth markets as atomic energy, turbines, missiles, aircraft, and process industries.

At the Fellowship Dinner, V. E. Zang, retiring as chairman of the Executive Committee, received an "Atmos" clock, a certificate of appreciation, and a perpetual registration card. A special honor, not given advanced publicity, was the award of a certificate to Ernest Kirkendall recognizing his services to the Electric Furnace Committee from 1946 to 1954.

K. D. Cassidy, group director, Body Group, Ford Motor Co. Dearborn, served as toastmaster. In words of greeting, the President of AIME, Augustus B. Kinzel, vice president of research, Union Carbide Corp., stressed the fact that well over half of the billions of dollars being spent on research today involves production of materials in electric furnaces.

Plant trips were held on the opening day of the conference. One group visited the Stainless Steel div. of Jones & Laughlin and witnessed the manufacture of quality sheet and strip. The second group went to Ford's Rouge plant and saw the ten-furnace open-hearth department, the rolling mills, and the stamping plant. A special feature was the assembly plant where 525 cars come off the assembly line every eight-hour shift. Assembly of each car takes 1 hr and 10 min. A car is driven off an assembly line every 55 sec under its own power.

Among those contributing to the success of the Sixteenth Electric Furnace Conference were O. G. Specht, Jr., and W. E. Hart, chairman and co-chairman of the Committee on Local Arrangements; A. C. Ogan and P. R. Gouwens, chairman and vice chairman of the Conference Committee; R. K. Kulp, principal organizer of the *Special Arc Group;* and V. E. Zang, chairman of the Executive Committee.

M. K. Schnurr, president, Stainless and Strip div., Jones & Laughlin Steel Corp., addresses the Fellowship Dinner as the featured speaker.

Calendar of Events of Metallurgical Society Activities at the AIME Annual Meeting

(All rooms are at St. Francis Hotel, unless otherwise noted)

Saturday, Februray 14

2:00 pm	Met. Soc. Board of Directors (Room 220)

Sunday, February 15

10:00 am	Met. Soc. Committee on Metallurgical Profession (Room 220)
2:00 pm	Met. Soc. Current Issues in Metallurgical Education (Italian Room)
4:30 pm	Joint Meeting of IMD Programs Committee and IMD Council of Technical Committees (Room 220)
5:00 pm	Council of Education Social Hour (Rose Room, Sheraton Palace Hotel)
6:00 pm	Council of Education Buffet Dinner (Rose Room, Sheraton Palace Hotel)
8:00 pm	Council of Education Technical Session (Concert Room, Sheraton Palace Hotel)

Monday, February 16

8:45 am	Get-together for Monday Authors and Session Chairmen (Colonial Room)
9:00 am	Met. Soc. Education Committee (Room 220)
9:30 am	IMD Symposium on Interfaces and Surfaces (California Room)
9:30 am	IMD Research Summaries on Interfaces and Surfaces (I) (Borgia Room)
9:30 am	ISD Iron Ore Reduction (Georgian Room)
10:00 am	EMD Electrolytic Extractive Processes (Colonial Room)
10:00 am	EMD Lead (Italian Room)
12:15 pm	IMD Chemistry and Physics of Metals Committee Luncheon Meeting (Room 220)
12:15 pm	IMD Titanium Committee Luncheon Meeting (Room 268)
2:30 pm	IMD Symposium on Direct Observations of Dislocations (California Room)
2:30 pm	IMD-EMD Symposium on Beryllium (Borgia Room)
2:30 pm	ISD-EMD Iron Blast Furnace Engineering (Georgian Room)
2:30 pm	EMD-IMD Plutonium-Extractive Metallurgy (Colonial Room)
2:30 pm	EMD Copper (Italian Room)
2:30 pm	IMD High Temperature Alloys Committee (Room 268)
3:30 pm	IMD Publications Committee (Room 221)
4:30 pm	IMD Membership Committee (Room 220)
4:30 pm	IMD Refractory Metals Committee (Room 268)
5:00 pm	ISD Physical Chemistry of Steelmaking Steering Committee (Room 221)

Tuesday, February 17

7:30 am	EMD Executive Committee Breakfast Meeting (Room 220)
8:15 am	Get-together for Tuesday Authors and Session Chairman (Colonial Room)
9:00 am	IMD Structural Materials Committee (Room 268)
9:00 am	IMD Research Summaries on Observations of Dislocations (California Room)
9:00 am	IMD Research Summaries on Mechanical Properties (Borgia Room)
9:00 am	EMD-IMD Plutonium-Physical Metallurgy (Italian Room)
9:00 am	EMD Symposium on Gases in Light Metals (Olympic Room)
9:00 am	ISD Basic Oxygen Steel (Colonial Room)
11:00 am	ISD Howe Memorial Lecture (Colonial Room)
12:15 pm	ISD Annual Luncheon and Business Meeting (Georgian Room)
12:15 pm	IMD Executive Committee Luncheon Meeting (Room 220)
4:00 pm	EMD High Temperature Metals Committee (Room 268)
6:00 pm	Met. Soc. Social Hour (Colonial Room)
7:00 pm	Met. Soc. Annual Dinner (Colonial Room)

Wednesday, February 18

7:30 am	ISD Executive Committee Breakfast Meeting (Room 220)
7:30 am	EMD Committee Chairmen Breakfast Meeting (Room 221)
8:15 am	Get-together for Wednesday Authors and Session Chairmen (Colonial Room)
9:00 am	EMD-ISD Kinetics in Extractive Metallurgy (California Room)
9:00 am	EMD Occurrence, Beneficiation, and Separation of Rare Earths (Italian Room)
9:00 am	EMD Zinc (Olympic Room)
9:00 am	IMD Research Summaries on Alloys Strengthening (Borgia Room)
9:00 am	IMD Research Summaries on Observations of Dislocations (Colonial Room)
10:45 am	IMD Annual Business Meeting (Colonial Room)
11:00 am	IMD Annual Lecture (Colonial Room)
12:15 pm	EMD Annual Stag Luncheon and Business Meeting (Georgian Room)
12:15 pm	ISD Physical Chemistry of Steelmaking Committee Luncheon Meeting (Room 220)
2:00 pm	EMD-ISD Applications of the Phase Rule in Extractive Metallurgy (California Room)
2:00 pm	EMD Rare Earth Metals (Italian Room)
2:00 pm	EMD-MBD Chemical Processes-Nickel (Comstock Room, Sheraton Palace Hotel)
2:00 pm	ISD Steelmaking Technology (Olympic Room)
2:00 pm	IMD Symposium on Scale Effects on Properties (Colonial Room)
2:00 pm	IMD Research Summaries on Interfaces and Surfaces (II) (Borgia Room)
3:00 pm	EMD Titanium, Uranium, and Uncommon Metals Committee (Room 220)
3:00 pm	EMD Physical Chemistry of Extractive Metallurgy (Room 221)
3:00 pm	Met. Soc. Publications Committee (Room 268)
5:00 pm	Met. Soc. Programs Committee (Room 220)

Thursday, February 19

8:15 am	Get-together for Thursday Authors and Session Chairmen (Colonial Room)
8:30 am	Met. Soc. Board of Directors Breakfast Meeting (Room 220)
9:00 am	IMD Symposium on Alloy Strengthening at Elevated Temperatures Part I—Solute and Impurity Effects (California Room)
9:00 am	IMD Research Summaries on Interfaces and Surfaces (III) (Borgia Room)
9:00 am	ISD Basic Science of Steelmaking (Georgian Room)
9:00 am	EMD Refractories (Italian Room)
9:00 am	EMD Chlorination Processes (I) (Colonial Room)
11:00 am	EMD First Extractive Metallurgy Division Lecture (Colonial Room)
12:15 pm	ASM Seminar Committee Luncheon Meeting (Room 220)
2:00 pm	IMD Symposium on Alloy Strengthening at Elevated Temperatures Part II—Dispersion and Precipitation Effects (California Room)
2:00 pm	IMD Research Summaries on Interfaces and Surfaces (IV) (Borgia Room)
2:00 pm	ISD Gas-Metal Research (Georgian Room)
2:00 pm	EMD Chlorination Processes (II) (Colonial Room)
2:00 pm	EMD-ISD Pyrometallurgical Processes (Italian Room)
2:00 pm	EMD-MBD Chemical Processes-Uranium (Comstock Room, Sheraton Palace Hotel)

EJC Honors Westinghouse for Scholarship Aid

The Engineers Joint Council, at a recent meeting of its board of directors, cited the Westinghouse Electric Corp. and the Westinghouse Educational Foundation, on the occasion of the twentieth anniversary of the George Westinghouse Scholarships to the Carnegie Institute of Technology. Each year, since 1938, ten specially selected high-school graduates have received full-tuition, four-year scholarships under the program.

The EJC citation, read by President E. R. Needles, commended Westinghouse and Carnegie for ". . their vision in recognizing the need to encourage talented young minds to seek careers in engineering, science, and management . . . [and] for establishing a pattern of scholarship help in engineering and scientific education which has provided many of the Nation's key industries and Government agencies with young men and women of outstanding caliber in their fields . . ."

Dr. J. A. Hutcheson, chairman of the Westinghouse Educational Foundation and vice president, Engineering, Westinghouse Electric Corp., accepted the award. In doing so, he made public the Foundation's latest project, a program where a unique piece of laboratory equipment is being offered to all colleges and universities that have accredited electrical engineering departments.

The Westinghouse scholarships, along with the much-acclaimed Westinghouse Science Talent Search, are truly pioneers in the field of cooperation between education and industry, and many other aid plans, both here and abroad, have used them as models.

Semiconductors Plans Boston Conference

Plans for the technical conference on Properties of Elemental and Compound Semiconductors, to be held in Boston at the Statler Hotel, August 31st to September 2nd, indicate that a successful meeting is in prospect, according to W. C. Hittinger, chairman of the IMD Semiconductors committee.

The Boston conference will include two days of technical sessions as well as a tour of Massachusetts Institute of Technology's Lincoln laboratories. The MIT lab, devoted to extensive research in many phases of electronics, recently produced the SAGE warning system for the US Dept. of Defense.

Technical sessions are to be evenly divided between invited and contributed papers. The invited session on Elemental Semiconductors will feature a panel discussion of the *Role of Dislocations in Device Properties*, with participants to include C. Mueller, Radio Corp. of America, A. E. Blakeslee, Bell Telephone Laboratories, and W. C. Dash, General Electric Co. In addition, the session will include papers on *Dislocations in Semiconductors*, by W. C. Dash, *Semiconductor Surfaces and Films*, by M. M. Atalla, and *Defect Interactions in Semiconductors*, by Howard Reiss, Bell Telephone Laboratories.

Listed for presentation in a second invited session devoted to Properties of Compound Semiconductors are the following papers: *Stoichiometry in Compound Semiconductors*, by W. W. Scanlon, Naval Ordnance Laboratories, *Properties of Silicon Carbide and Gallium Phosphide for Power Rectifiers*, by Robert Davis, Westinghouse Electric Corp., *Compound*

(Continued on page 144)

Award Winners

(Continued from page 140)

achievement in mining other than coal: to John B. Knaebel. A graduate of Cornell and Stanford Universities, Mr. Knaebel was responsible for the first successful large-scale uranium mining and milling operation in North America. His work has carried him to Central America, British Columbia, the Philippines, and Brazil. In 1956 he was appointed assistant to the vice president in charge of mining operations, The Anaconda Co. He became a consultant in 1958.

Oliver Bowles Honored Posthumously with First Hardinge Award

The late Oliver Bowles was honored posthumously on December 2nd with the presentation of the first *Hal Williams Hardinge Award*. Mrs. Bowles accepted the engraved plaque for her husband at President's Night of the Washington, D. C. section. The award recognizes outstanding achievement in the field of industrial minerals.

Dr. Bowles was born in Ontario, Canada. His enthusiasm for quarrying drew him to the US after he graduated from the University of Toronto. In 1914 he joined the US Bureau of Mines, remaining there until his retirement in 1947. He received the Distinguished Service Award of the US Dept. of Interior for his outstanding career as a specialist on nonmetallic minerals in 1948.

Edgar C. Bain Awarded Ambrose Monell Medal

Dr. Edgar C. Bain, retired vice president in charge of research and technology, U.S. Steel Corp., has been awarded the *Ambrose Monell Medal* for distinguished achievement in mineral technology.

Dr. Bain is responsible for establishing the scientific basis of heat treating steel. He was one of the first scientists to use X-ray diffraction techniques in the systematic study of alloys.

The Monell Medal was established in 1954 at the Columbia School of Mines in honor of Ambrose Monell, first president of the International Nickel Co. Mr. Monell died in 1922. The copper-nickel alloy, *monel*, was named for him.

Dr. Bain was the recipient of the *Robert W. Hunt* (Gold) *Medal and Prize Fund* in 1929, and was the Howe Memorial Lecturer in 1932.

Semiconductors

(Continued from page 143)

Semiconductors for Transistors or Transistor-like Devices, by L. Weisberg, RCA, and *New Compound Semiconductors*, by Jack Wernick, Bell Telephone Laboratories.

Authors were invited to contribute papers to the conference through a call for papers in January's JOURNAL OF METALS. Prospective authors may still submit abstracts for consideration. They should be limited to 150 words, and submitted before March 1, 1959, to *W. C. Hittinger, Bell Telephone Laboratories, 555 Union Boulevard, Allentown, Pa.*

Powder Metallurgists Increase Publication

The Powder Metallurgy committee of the IMD has announced a change in the publication of their *Newsletter*. Edited by Henry H. Hausner, the *Newsletter* is being increased to 8 pages. Five releases are scheduled during the year. Members of AIME will receive the issues upon request. Subscription rate for nonmembers is $2.00 per year. Requests may be addressed to: *Secretary, The Metallurgical Society of AIME, 29 West 39th St., New York 18, N. Y.*

Powers Nominated for Blast Furnace Chair

The Nominating committee of the Blast Furnace, Coke Oven, and Raw Materials committee, ISD, has placed in nomination the following men for terms beginning in April 1959: R. E. Powers, chairman; James Chisholm, vice chairman; F. G. Anderko, vice chairman; W. F. Huntley, secretary.

Director for a four year term is J. S. McMahan. The nomination of James Chisholm fills the unexpired term of the late Clarence Corban.

Subscription Rates Increase this Month

Effective Feb. 1, 1959, non-member subscriptions to the JOURNAL OF METALS and TRANSACTIONS OF THE METALLURGICAL SOCIETY OF AIME have been increased to meet publication costs. The new prices are printed below:

Journal of Metals	
Non-member, domestic	$10.00
Single copy, member and non-member	$1.50
Library subscription	no discount
Transactions	
Non-member, domestic, bound volume	$25.00
Non-member, foreign, bound volume	$30.00
Library subscription	no discount

PERSONALS

Named as manager of engineering services for refractories div. of H. K. Porter Co. Inc.: **Wilfred H. Stewart.** Mr. Stewart has been with the Sunbeam Corp.

Added to the staff of the research laboratory of The International Nickel Co. Inc., at Bayonne, N. J.: **Mrs. Laurence Pellier,** a specialist in the application of electron microscopy to problems of physical metallurgy.

OBITUARIES

Edwin T. Goodridge (member 1948) passed away on Nov. 20, 1958. At the time of his death, he was a consultant living in Princeton, N. J. Prior positions were as president of Horizons Inc., Princeton, and vice president of Titanium Alloy Mfg. Co., N.Y.C.

James O. Lord (member 1937), professor of metallurgy, Ohio State University, died on Oct. 13, 1958. Professor Lord was educated at Ohio State University, graduating with a B. Ch. E in 1915, and returning as an instructor in 1921. Between 1915 and 1921 he worked as

Change of Address and Personals Form

To be sure that you receive your publications and correspondence promptly, please fill in the form below and send it to **The Metallurgical Society of AIME**, 29 W. 39th St., New York 18, N.Y.:

Name _____

Old Address _____

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Personals: Please list below your former company and title and your new title and company (or new work) for use in JOURNAL OF METALS. (Copy deadline for personals items is six weeks before date of issue.)

Former Company _____

Former Title _____ Length of Time There _____

New Company _____

New Title _____ Date of Change _____

Any recent activity that would be of interest to members:

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PROPOSAL FOR AIME MEMBERSHIP

I consider the following person to be qualified for membership and request that a membership kit be mailed to him:

Name of Prospective Member:

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Address

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JM

a chemical warfare officer in the Army and as assistant metallographer with the Illinois Steel Co. in Gary.

James T. MacKenzie (member 1924) died suddenly on Nov. 17, 1958 in Birmingham, Ala. Chairman of ISD in 1938 and Howe Memorial lecturer in 1944, Dr. MacKenzie was graduated from the University of the South in 1911. The university conferred upon him the honorary degree of doctor of science in 1930 and elected him a member of the board of trustees in 1946. Dr. MacKenzie joined the American Cast Iron Pipe Co. as an analyst in 1912 and later served as chief chemist and metallurgist.

William J. Morrow (member 1940) passed away on Aug. 23, 1958. A graduate of the University of Wisconsin, Mr. Morrow had been associated with The American Brass Co., Kenosha, Wisc., since 1931. He became technical supervisor in 1939.

Curtis Pigott (member 1914) died on Nov. 29, 1958. A graduate of Yale and Columbia, Mr. Pigott was associated for a long time with the Phelps Dodge Refining Corp. on Long Island, N. Y.

Frank F. Poland (member 1951) passed away on Nov. 16, 1958. Mr. Poland was manager of the furnace dev. div., Revere Copper & Brass Inc., research dept., Rome, N. Y. While he was with the American Smelting & Refining Co., he developed and obtained patents on the continuous casting of copper. Two of his papers have been published by The Metallurgical Society.

NECROLOGY

Date Elected	Name	Date of Death
1944	Anderson, Alfred T.	Nov. 9, 1958
1957	Bailey, Rush	Apr. 21, 1958
1953	Barbour, Russell C., Jr.	Nov. 1957
1914	Batten, Harold L.	July 9, 1958
1905	Blomfield, Alfred L. (Legion of Honor)	Oct. 19, 1958
1942	Corban, Clarence L.	May 1958
1914	Crane, Clinton H.	Dec. 1, 1958
1939	Daggett, Ephraim B.	Oct. 28, 1958
1945	Drenan, John R.	July 14, 1958
1940	Fish, Russell C.	Nov. 12, 1958
1941	Gates, Lauren A.	Nov. 24, 1958
1948	Goodridge, Edwin T.	Nov. 20, 1958
1916	Hobart, Robert E.	June 1958
1946	House, John W.	Oct. 10, 1958
1951	Inman, John J.	May 10, 1958
1917	Lindley, Curtis, Jr.	Feb. 1958
1917	Lord, James O.	Oct. 1., 1958
1956	Lundin, Richard C.	Nov. 13, 1958
1924	MacKenzie, James T.	Nov. 17, 1958
1952	Martin, John L.	Mar. 22, 1957
1940	Morrow, Wm. J.	Aug. 23, 1958
1944	Nelson, Herbert D.	Sept. 30, 1958
1917	Nolan, Philip E.	Nov. 28, 1958
1948	Nowlan, Harry H.	Nov. 20, 1958
1904	Paymal, George W. (Legion of Honor)	Mar. 30, 1958
1956	Peterson, Warren M.	Aug. 19, 1958
1914	Pigott, Curtis	Nov. 29, 1958
1950	Poland, Frank F.	Nov. 16, 1958
1897	Prosser, Herman A. (Legion of Honor)	Nov. 22, 1958
1946	Ruhl, Otto	June 21, 1958
1949	Shilcutt, Charles E.	Nov. 1, 1958
1921	Shugert, Joseph L.	Mar. 21, 1958
1915	Skeels, Frank H.	Nov. 20, 1958
1920	Stewart, Wm. H.	Aug. 7, 1958
1937	Wardell, Henry R.	Nov. 15, 1958
1950	Willson, Charles O.	Sept. 19, 1958

Herman A. Prosser (member 1897) died in New York City on Nov. 22, 1958. A graduate of Columbia University, Mr. Prosser was a former vice president of the American Smelting & Refining Co. in New York. His home was in Greenwich, Conn.

MEMBERSHIP

Proposed for Membership
Metallurgical Society of AIME

Total AIME membership on Nov. 1, 1958 was 30,815; in addition 3,279 Student members were enrolled.

ADMISSIONS COMMITTEE

J. H. Scaff, Chairman; Alfred Bornemann; F. B. Foley; T. D. Jones; L. L. Seigle; J. M. Warde; H. K. Work.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

Members

Andreychek, Sergius D., Pittsburgh, Pa.
Barbour, Fred C., Cleveland, Ohio
Barnum, Harold E., Detroit, Mich.
Bourgault, Roy F., Worcester, Mass.
Brand, William N., Pittsburgh, Pa.
Brutcher, Henry E., Altadena, Calif.
Carosella, Michael C., Niagara Falls, N. Y.
Carter, John T., New York, N. Y.
Cope, Gerald R., Johnstown, Pa.
Cuke, Norman H., Sorel, Quebec, Canada
Donnelly, Robert W., Harvey, Ill.
Fathers, Frank, Montreal, Quebec, Canada
Feathers, William H., New York, N. Y.
Finkl, Charles W., Chicago, Ill.
Goller, George N., Baltimore, Md.
Grant, George, III, Midland, Mich.
Hahmann, Heinz, B., S. Paulo, Brazil
Harris, Max, Johannesburg, S. Africa
Horvay, Gabriel, Schenectady, N. Y.
Jacobsen, William B., Chicago, Ill.
Johnson, Neal J., New York, N. Y.
Johnson, Thomas E., Milwaukee, Wisc.
Kattus, James R., Birmington, Pa.
Keefe, Robert M., Shelton, Conn.
Levenson, Milton, New York, N. Y.
Liebmann, Bernhard G., Providence, R. I.
Large, Frank E., Calvert City, Ky.
Lund, Russell T., Calvert City, Ky.
March, Eugene A., Midland, Pa.
McDonald, Allen S., Fairfield, Conn.
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Molnar, Louis, Hammond, Ind.
Montgomery, Allen M., Cleveland, Ohio
Mooradian, Victor G., Union, N. J.
Moyer, Charles E., Hamburg, N. Y.
Orban, Edward, St. Louis, Mo.
Sherrill, John G., Houston, Texas
Slader, Wilfred A., Indiana Harbor, Ind.
Stevens, Leo J., Chicago, Ill.
Stingel, Donald E., Riverside, Conn.
Stitt, Robert E., Pittsburgh, Pa.
Thompson, Robert, Lachine, Quebec, Canada
Thurman, Astor L., Huntington, W. Va.
Weeton, John W., Cleveland, Ohio
Woodburn, James, Jr., Chicago, Ill.
Work, Josiah, Darien, Conn.

Associate Members

Beidler, Clarence H., Canton, Ohio
Cornelssen, C. William, Jr., Springfield, Pa.
Evans, Marcus, Rockwood, Tenn.
Feerrar, LaRue R., Philadelphia, Pa.
Finn, John A., Abington, Pa.
Hart, Ronald G., South Bend, Ind.
Harvey, Erie M., Greensboro, N. C.
Hill, H. E., New York, N. Y.
Keeffe, Edwin J., Cleveland, Ohio
Lawrence, Robert, Jr., New York, N. Y.
McDermott, Thomas H., Lansing, Ill.
Mitchell, James, Philadelphia, Pa.
Schweinsberg, Harry S., Pittsburgh, Pa.
Snowhill, Thomas B., Gresham, Ore.
South, Richard C., Pittsburgh, Pa.
Tomaszewski, Constatine E., Detroit, Mich.
Vaughan, John W., Davenport, Iowa
Wilson, James G., Huntington, W. Va.

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Angus, John C., Ann Arbor, Mich.
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Doble, Gordon S., Cleveland, Ohio
Fraser, Robert W., Edmonton, Alberta, Canada
Goheen, Ross W., Cicero, Ill.
Hartley, Craig S., Watertown, Mass.
Hathaway, Jerry M., Massillon, Ohio
Jungers, Robert H., Columbia Falls, Mont.
Laverty, David P., Cleveland, Ohio
Lund, Arne W., Toronto, Ontario, Canada
Meakin, John D., Philadelphia, Pa.
McIntyre, Ruliff D., Cleveland, Ohio
Robinson, George C., Jr., Farmington, Conn.
Schreiner, William A., Pittsburgh, Pa.
Stoner, Donald R., Greensburg, Pa.
Thomas, Kenneth C., Pittsburgh, Pa.

CHANGE OF STATUS

Student to Junior

Miller, Ronald A., Parma, Ohio

Junior to Associate

Beaver, Howard O., Jr., Reading, Pa.
Eichelman, George H., Jr., Waterbury, Conn.
Gage, Walter L., Blackwell, Okla.
Gilman, John J., Schenectady, N. Y.
Steinbrenner, Walter L., Pittsburgh, Pa.

Junior to Member

Baker, Douglas, Kellog, Idaho

SPECIAL REINSTATEMENT

Student

Cuddy, Lee J., New York, N. Y.

RE-ELECTION

Bevelheimer, F. Bruce, Pittsburgh, Pa.

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Experimental Designs Data Analysis
1130 Woodlawn Street, Bethel Park, Pa.
Telephone: TEnnyson 5-5241 (Pittsburgh)

Coming Events

Feb. 13, AIME Southwestern Local Section, Winter meeting, St. Louis, Mo.

Feb. 15-19, AIME Annual Meeting, St. Francis Hotel, Sheraton-Palace Hotel, and Sir Francis Drake Hotel, San Francisco.

Mar. 5. AIME, NOHC Cleveland Section, meeting, Rockside Gardens, Cleveland.

Mar. 11, AIME, NOHC, Chicago Local Section, All-day Off-The-Record Meeting, Del Prado Hotel, Chicago.

Mar. 12, AIME, NOHC Northern Ohio Local Section, Annual technical meeting, Pick-Ohio Hotel, Youngstown, Ohio.

Mar. 16-20, Western Metal Exposition and Congress, Pan-Pacific Auditorium, Los Angeles, Calif.

Apr. 2-3, AIME National Conference on Physical Metallurgy of Stress Corrosion Fracture, Mellon Institute, Pittsburgh, in cooperation with the Electrochemical Society, American Society for Testing Materials, and National Society of Corrosion Engineers.

Apr. 5-10, Fifth Nuclear Congress, Cleveland Auditorium, Cleveland.

Apr. 6-8, AIME 42nd National Open Hearth Steel Conference and Blast Furnace, Coke Oven, and Raw Materials Conference, Jefferson Hotel, St. Louis.

Apr. 16-18, AIME Northwest Regional Conference, Olympic Hotel, Seattle, Wash.

Apr. 22-26, Annual spring meeting of the Metal Treating Institute, Hollywood Beach Hotel, Hollywood, Florida.

Apr. 27-30, AIME International Symposium on the Physical Chemistry of Process Metallurgy, Penn-Sheraton Hotel, Pittsburgh.

May 4, AIME, NOHC Chicago Local Section, Spring meeting at Phil Smidt's Restaurant, Hammond, Ind.

May 14, NOHC Cleveland Section, meeting, Rockside Gardens, Cleveland. Topic: Basic Roof.

May 21-22, AIME New England Regional Conference, Statler Hotel, Hartford, Conn.

June 5, AIME, NOHC Southern Ohio Section. Golf Outing, Summit Hills Country Club, Fort Mitchell, Kenton County, Ky.

June 20, NOHC Cleveland Section, Dinner-Dance, Lake Shore Hotel, Cleveland.

Aug. 31-Sept. 2, Semiconductors Conference, Statler Hotel, Boston, Mass.

Oct. 16-17, NOHC Southern Ohio Section, Fall Meeting, Deshler-Hilton Hotel, Columbus, Ohio.

Nov. 2-6, Fall Meeting of The Metallurgical Society of AIME, International Ampitheatre, Chicago, Ill., Morrison Hotel, Chicago.

Dec. 2-4, AIME Cleveland Section, 17th Electric Furnace Steel Conference, Hotel Cleveland, Cleveland, Ohio.

Feb. 14-18, 1960, AIME New York Section, Annual Meeting, Hotel McAlpin and Hotel Statler, New York.

Apr. 4-6, 1960, AIME 43rd National Open Hearth Steel Conference and Blast Furnace, Coke Oven, and Raw Materials Conference, Palmer House, Chicago.

June 13-15, 1960, first International Powder Metallurgy Conference, Hotel Biltmore, New York, under joint auspices of AIME and MPI.

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JOURNAL OF

METALS

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The Metallurgical Society
of
American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc.

29 West 39th Street, New York 18, N. Y.

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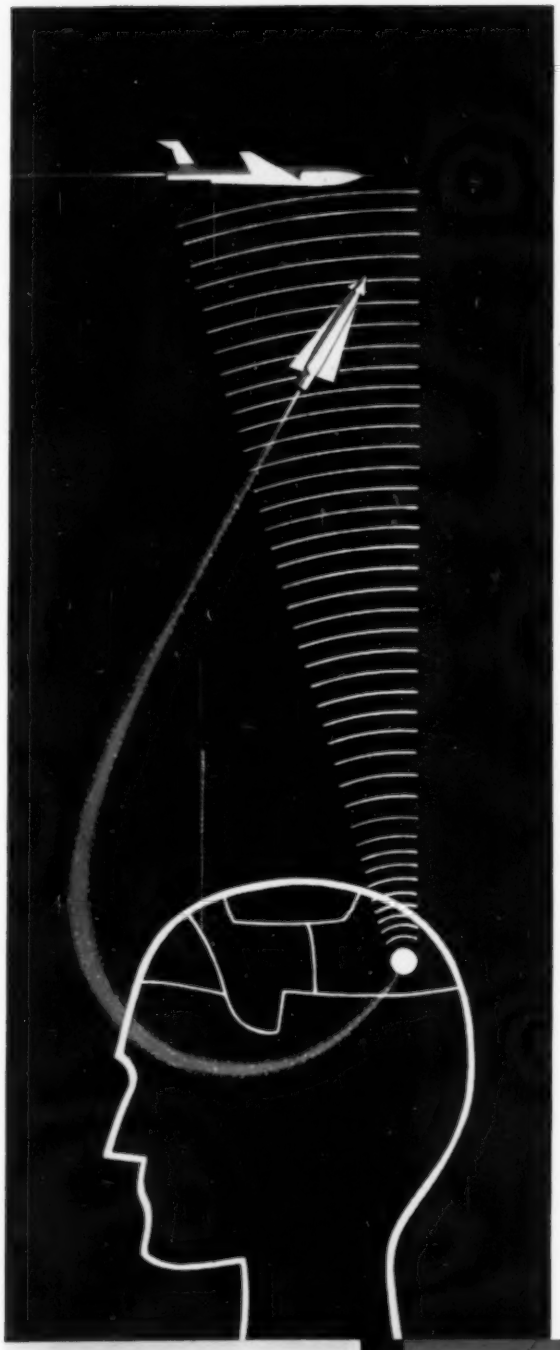

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